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The Effect of Transannular Interactions in Medium Ring Cationic Reaction Intermediates.

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THE EFFECT OF TRANSANNULAR INTERACTIONS IN MEDIUM RING CATIONIC REACTION INTERMEDIATES

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To my wife, Karen

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ABSTRACT

The effects of transannular interactions, common to medium rings, are studied with particular interest focused on transannular hydride shifts and transannular eliminations in carbonium ion reaction intermediates.

The chlorinolysis of deuterium labeled cycloalkyl 2,4-dinitrobenzenesulfenates (ring sizes 8 and 10) in acetic acid has made it possible to characterize transannular hydride shifts occuring in intermediate ion pairs. The dependence of product distributions on lithium perchlorate salt has led to the conclusion that chloride product arises from intimate ion pairs, whereas acetate appears to evolve from a solvent-separated intermediate. The deuterium scrambling in the products suggests that transannular hydride shifts occur to nearly the same extent in both ion pair species.

The generation of solvolytic, medium ring carbonium ions (ring sizes 8 and 10) in solvents of low nucleophilicity (2,2,2-trifluoroethanol and trifluoroacetic acid) has also been studied. The product distribution data reveal that the energy of intermediate carbonium ions is higher than that of normal solvolytic cations, but not as high as that achieved in reactions involving "hot" cationic intermediates.

PART ONE

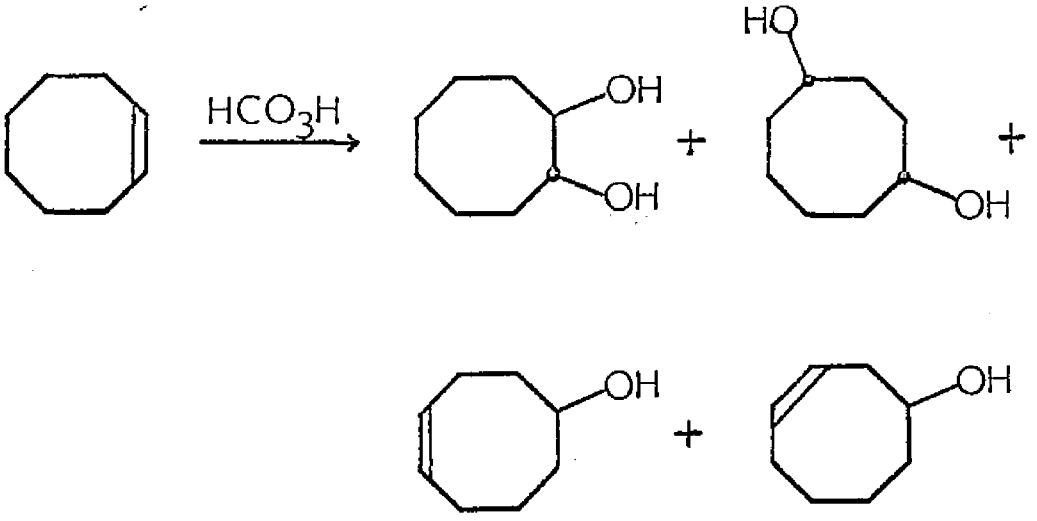
The Chlorinolysis of Medium Ring Cycloalkyl 2,4-Dinitrobenzenesulfenates in Acetic Acid: Transannular Hydride Shifts

I. INTRODUCTION

A. Transannular Hydride Shifts

Medium rings (eight to eleven carbon atoms)[1] have been distinguished from other carbocyclic ring systems on the basis of their unique physical properties. Not until recent years[2,3] was the synthesis of medium rings satisfactorily effected. This difficulty is obvious when one realizes the relatively high strain energies associated with medium rings in comparison to common (five and six carbon atoms) and large (twelve or more carbon atoms) rings.[4] Unlike cyclohexane, a medium ring cannot both accommodate tetrahedral bond angles and minimize hydrogen-hydrogen interactions by existing in a regularly staggered conformation. This inability to assume a strainless conformation is responsible for a 9.6-12.6 kcal/mole strain on medium rings[4] (relative to cyclohexane being strain free). The sources of this large strain include Pitzer strain (vicinal repulsions), Baeyer strain (valence bond angle deviation), and "transannular strain", which is the strong end-on repulsion between hydrogens in transannular positions. This medium ring strain has been referred to as "I-strain" (internal strain).[5] X-ray crystallography is a useful empirical means for conformational studies of medium rings and has borne out the theoretical assumptions that large bond angle deformations and transannular repulsions exist.[6-9]

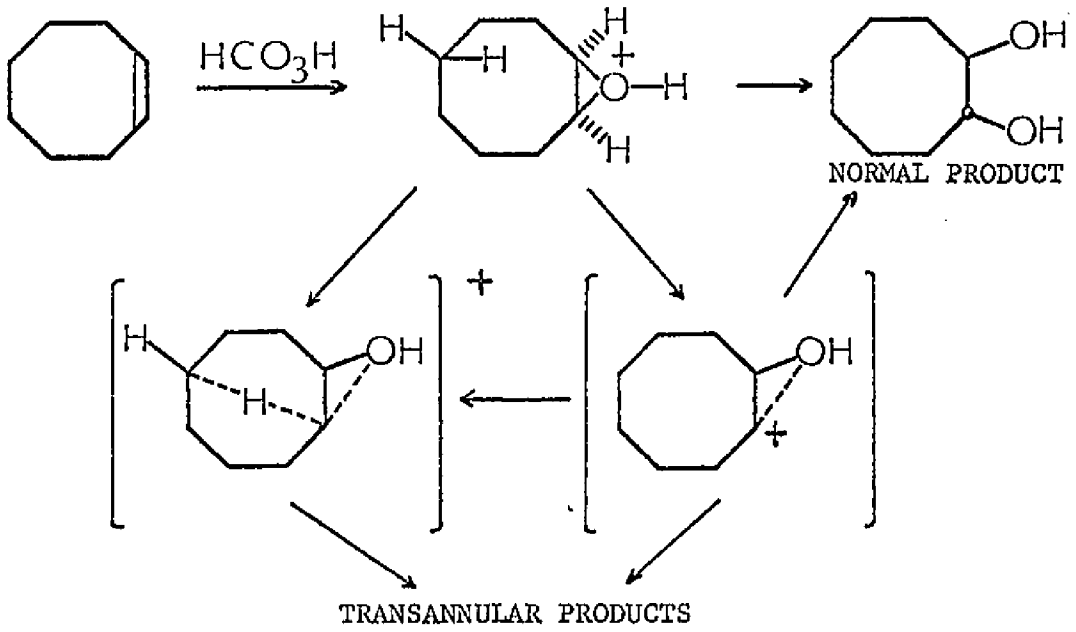
These physical properties which are common to all the medium rings are responsible for the development of an interesting body of chemistry.[10,11] In particular, the close proximity of transannular positions, which are responsible for the "transannular strain" described above, enable medium ring carbonium ions to undergo hydride shifts across the ring. In 1952, the first observations of transannular reactions were reported independently by Cope[12] and Prelog[13] for the peroxyformic acid oxidations of cis-cyclooctene and cis-cyclodecene, respectively. Each mixture consisted of major portions



of transannular diols and enols instead of only the expected 1,2-trans diol. These rearrangements can be rationalized by the following scheme:[11]

SCHEME I

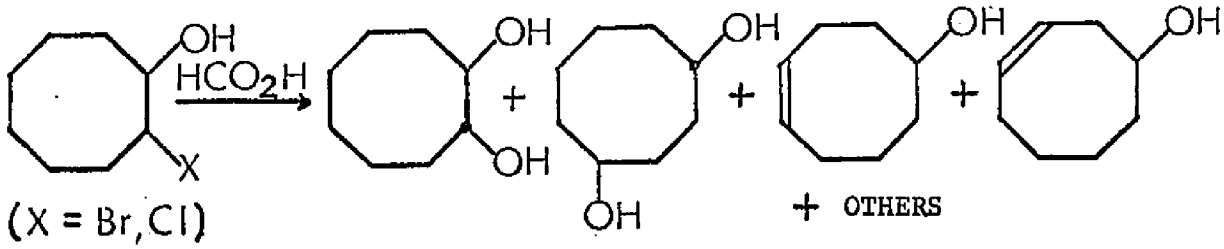
THE MECHANISM FOR TRANSANNULAR PRODUCT FORMATION IN THE PERFORMIC ACID OXIDATION OF cis-CYCLOOCTENE



(a 1,3-hydride shift may also be envisioned as an intermediate rearrangement)

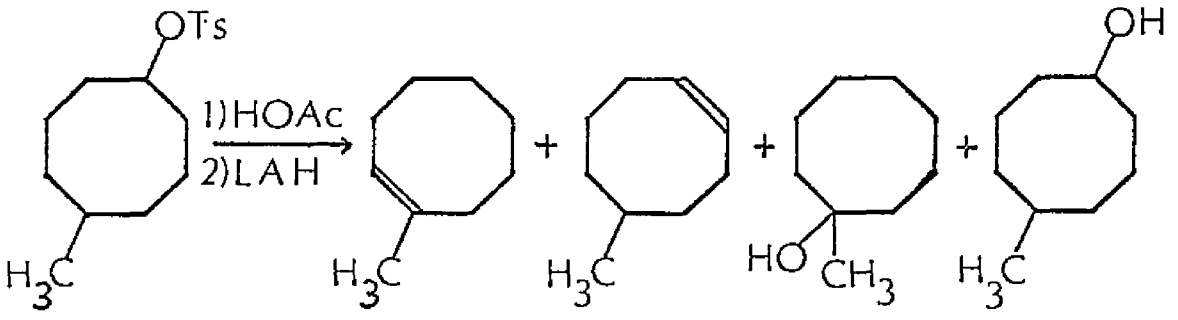
By decreasing the nucleophilicity of the solvent, that is, increasing the lifetime of the intermediate cation, up to one hundred per cent transannular rearrangement has been observed.[14]

This propensity for medium ring cycloalkyl cations to undergo a transannular hydride shift is greatly enhanced by the presence of an adjacent, electronegative, destabilizing substituent such as the hydroxyl group above. Solvolyses of 2-halocycloalkanols have similarly yielded substantial amounts of transannular products.[15,16]



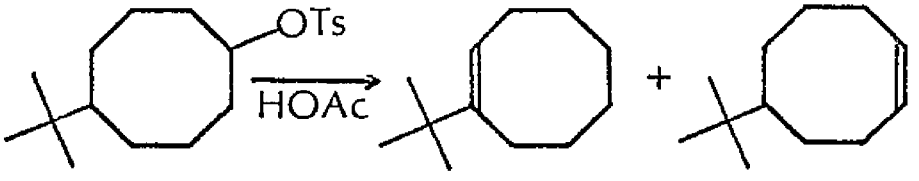
Other destabilizing groups such as tosylate[17] (p-toluenesulfonate), and bromide[18] have also been found to facilitate transannular reaction.

It is also possible to promote transannular hydride shifts by situating an electron releasing group at a transannular site. Such an example would be the solvolysis of 5-methylcyclooctyl tosylate.[19]



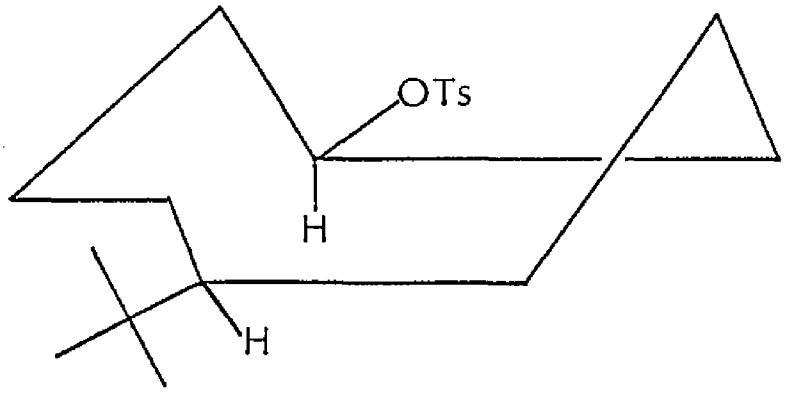
cis	84	10	5.5	0.5
trans	8	74	1	15

The strong dependence of rearrangement on the stereochemistry of the starting substrate is obvious. Allinger has shown that in the solvolysis of 5-t-butylcyclooctyl tosylate,[20] the effect of the t-butyl group on the conformation of the rings is so great that nearly all of the reaction of the cis isomer proceeds via a transannular pathway.



cis	99	1
trans	11	89

The most stable conformation for the cis isomer is believed to be a boat conformer, with both substituents in equatorial positions.



The ease with which the hydride in position 5 can migrate is apparent, whereas the trans isomer cannot assume as favorable a geometry for hydride migration. Substantial transannular hydride shift is also observed when a phenyl substituent is present at the 5 position.[21]

All of the examples of transannular hydride shifts hitherto cited have a pronounced, innate driving force favoring rearrangement. However, there exists substantial evidence for transannular hydride shifts in medium ring carbonium ions on which there is not present a substituent(s) which greatly affects the chemistry of the ring.[10,22,23] Isotopic labeling (carbon-14 and deuterium) has proven to be a useful means for studying these rearrangements.

Most of the data at hand have been extracted from the acetolyses of cycloalkyl para-substituted benzenesulphonates. Table I summarizes the data available on transannular hydride shift for such solvolysis reactions. It is obvious that the extent of rearrangement is minimal in 7- and 12-membered rings and is appreciable, even in unsubstituted systems, in medium rings.

TABLE I

PERCENT TRANSANNULAR HYDRIDE SHIFT IN PRODUCTS FROM THE ACETOLYSIS OF CYCLOALKYL p-X-BENZENESULFONATES

Cycloalkyl, Ring Size	X in p-X-$C_6H_4SO_3R$	------Reaction Products------ cis-Olefin	trans-Olefin	Acetate	Ref
7[a]	CH_3	≤ 3.5	--	≤ 4.5[c]	10
8[b]	Br	49	--	55	22
9[a]	CH_3	26	21	23[c]	10
10[a]	CH_3	29	12	---	10
10[d]	CH_3	---	16	---	23
11[a]	CH_3	---	11	---	10
12[a]	CH_3	≤ 0.2		---	10

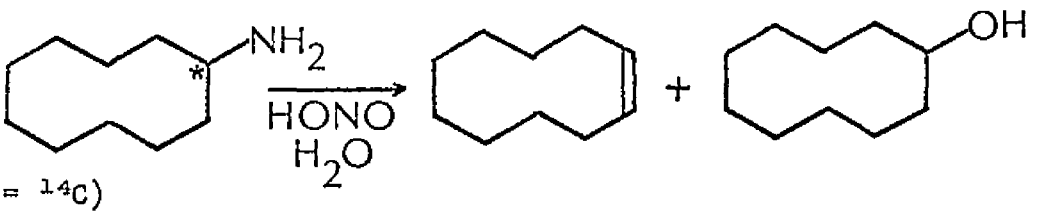
a. Carbon-14 labeled substrates (activity in β as well as α position).

b. Pentadeuterium labeled substrate (deuterium in α and β positions).

c. Isolated as alcohol.

d. Monodeuterium labeled substrate (deuterium in α position).

Carbonium ions from other precursors, such as diazonium ions, have also exhibited transannular hydride shifts.[10]



(* = ^{14}C)

% TRANSANNULAR HYDRIDE SHIFT: 16.5% 25%

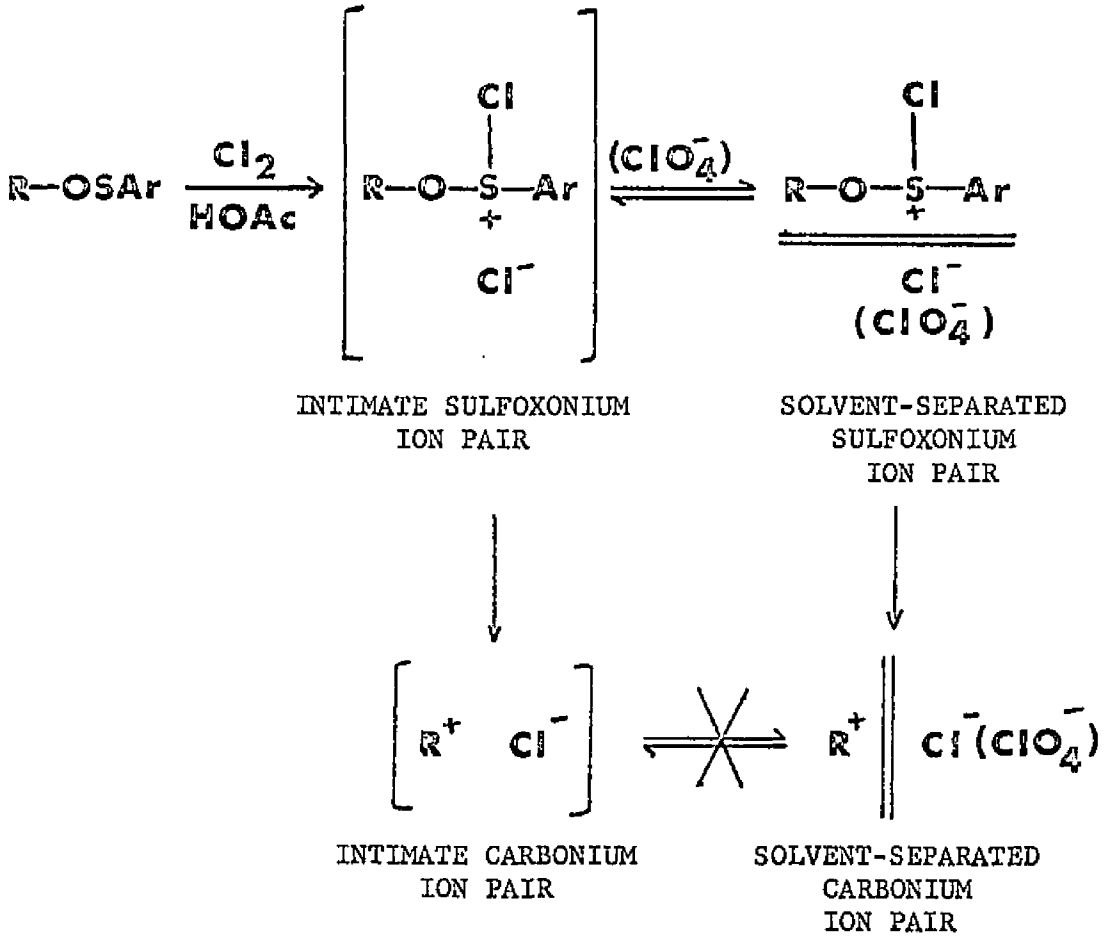
As might be expected, the amine deamination yields different products than the tosylate solvolysis. The amount of rearrangement in the cis-olefin has dropped off considerably when compared to that formed in the solvolysis, probably a reflection of the short lifetime of this carbonium ion intermediate.

B. Chlorinolysis of Alkyl 2,4-Dinitrobenzenesulfenates in Acetic Acid

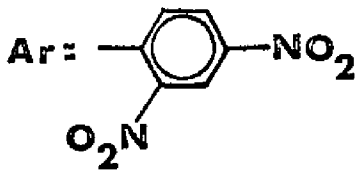
The chlorinolysis of alkyl 2,4-dinitrobenzenesulfenates in acetic acid has been shown to be a useful tool in mechanistic studies of ionic reactions, as extensive characterization of ion pairing behavior has been made in a number of systems.[24-28] Generally, the arenesulfenate is chlorinated to form an intimate sulfoxonium ion pair which may lose a sulfinyl chloride fragment to form the corresponding carbonium ion pair, or undergo solvent reorganization to form other sulfoxonium ion pairs. The resulting carbonium ions (which form chloride, acetate, and olefin products) are believed to inherit the solvent structure of their respective sulfoxonium ion precursors[24] (see Scheme II).

SCHEME II

THE CHLORINOLYSIS OF ALKYL 2,4-DINITROBENZENESULFENATES IN ACID



R = alkyl

Ar: 

The "special salt" effect,[27] which is manifested by a change in product distribution when lithium perchlorate is present in the reaction medium, has led to the conclusion that chloride is a product of intimate ion pairing, whereas acetate is formed from solvent-separated ion pairs. Since perchlorate anion has the ability to prevent return to intimate ion pairs from solvent-separated ion pairs, the overall effect may be seen as an enhancement of the latter species. Therefore, increase in acetate product at the expense of chloride, when lithium perchlorate is present, indicates that acetate arises from reaction of solvent-separated ion pairs, and chloride comes from an intimate ion pair intermediate.

It was believed that the chlorinolysis of cycloalkyl 2,4-dinitrobenzenesulfenates in acetic acid might provide useful information concerning transannular hydride shifts occurring in intermediate medium ring carbonium ion pairs.

II. RESULTS AND DISCUSSION

All cycloalkyl 2,4-dinitrobenzenesulfenates were prepared from the corresponding cycloalkanols and 2,4-dinitrobenzenesulfenyl chloride.[28] Each ester was a neatly crystalline, brightly yellow material, stable for extended periods of time at room temperature. The reaction of cycloalkyl arenesulfenates with a 2.5-3 molar excess of chlorine in acetic acid gives cycloalkyl chlorides, acetates, and elimination products (which add chlorine), and presumably 2,4-dinitrobenzenesulfinyl chloride as the aromatic fragment. Excess chlorine oxidized the sulfinyl chloride to sulfonyl chloride, a reaction which occurred during the work-up procedure when water was added.

$$ArS(O)-Cl + H_2O + Cl_2 \rightarrow Ar-S(O)_2-Cl + 2HCl \qquad \text{(ref 24)}$$

Efforts to avoid addition of chlorine to cyclooctene were unsuccessful as the rate of addition was apparently very fast and preceded complete chlorinolysis of the arenesulfenate. As the chlorine was added to the acetic acid reaction medium, the intense yellow-orange color of the solution dissipated, and the slightly greenish color of the chlorine solution remained. When water was added, an immediate precipitate formed which was believed to be the sulfonyl chloride. The yields of sulfonyl chloride were low due to the extreme difficulty of quantitative recovery from the glassware and also due to its partial solution in pentane during extraction. The results for the chlorinolysis of cyclooctyl and cyclodecyl 2,4-dinitrobenzenesulfenates are shown in Tables II and III, respectively. The effect of added lithium perchlorate on the product

TABLE II

PRODUCT DISTRIBUTION FROM THE CHLORINOLYSIS OF CYCLOOCTYL 2,4-DINITROBENZENESULFENATE

RUN	$[LiClO_4]$ (mole/liter)	CHLORIDE	ACETATE	OLEFIN ADDITION PROD. 1,2-TRANS DICHLORIDE	OTHERS[b] (5)	YIELD[a]
1	----	61	14	13	12	---
2	----	58	18	12	12	78%
3	----	60	17	12	11	70%
4	0.08	15	38	24	23	74%
5	0.08	13	39	25	23	---

a. Calculated on the basis that the unidentified products are isomeric (transannular) dichlorides. Yields could not be determined on the basis of isolated sulfonyl chloride, as quantitative separation of the solid could not be effected.

b. These components (5) were also shown to arise from the addition of chlorine to cyclooctene in acetic acid (see Table VI).

TABLE III

PRODUCT DISTRIBUTION FROM THE CHLORINOLYSIS OF CYCLODECYL 2,4-DINITROBENZENESULFENATE IN ACETIC ACID[a]

RUN	$[LiClO_4]$ (mole/liter)	CHLORIDE	ACETATE	CHLORIDE / ACETATE	OLEFIN[b] AND ADDITION PRODUCTS[c]
1	----	36	> 4	8.8/1	60
2	----	> 38	6	6.4/1	56
3	0.08	5	6	0.84/1	89
4	0.08	5	10	0.50/1	85
5	0.08	6.5	6.5	1.00/1	87

a. Gas chromatographic (gc) area %'s are reported here; however, chloride and acetate have essentially the same molar response.

b. A mixture of cis- and trans-cyclodecene.

c. There was found to be present 13 addition products, the only identified component being trans-1,2-dichlorocyclodecane, which constituted 25-35% of the olefin and addition products. These were shown to be addition products by comparing gc chromatograms with those obtained for the addition of chlorine to cis- and trans-cyclodecenes (see Experimental Section).

distribution was also studied for both cyclooctyl and cyclodecyl arenesulfenates; these results appear in Tables II and III also.

The effect of added lithium perchlorate on the ratio of chloride/acetate and chloride/olefin products is quite obvious. Without lithium perchlorate, the chloride product strongly predominates; however, in its presence the yield of chloride drops off sharply and the yields of acetate and olefin increase noticeably, the shift in chloride/acetate being about ten-fold for both systems studied.

These data suggest that acetate and olefin arise mainly from the solvent-separated ion pairs, whereas chloride is a product of the intimate ion pair intermediate. This interpretation seems reasonable when one considers the close proximity of the cycloalkyl carbonium ion and the chloride anion in the intimate pair. Collapse to the covalent chloride should occur much more readily than reaction with solvent. In the absence of added lithium perchlorate, the presence of great numbers of intimate ion pairs will be responsible for a large yield of cycloalkyl chloride. On the other hand, in the presence of lithium perchlorate, the amount of intimate ion pairs is greatly reduced and the predominating reactive species is one with its carbonium ion center surrounded by acetic acid molecules which are much closer than the chloride gegenion, and reaction occurs to form acetate.

The increase in the acetate portion of the cyclodecyl products, in the presence of lithium perchlorate is small; however, the ratio of acetate/olefin is about the same as that in the absence of the salt. This great preference of elimination over substitution is simply a reflection of the high strain associated with the 10-membered ring.[4]

Nucleophilic attack of solvent at the sp^2 carbonium ion center to form an sp^3 hybrid bond is far less favorable energetically than loss of a proton to form olefin, which incorporates two sp^2 bonds in the molecule. sp^2 hybrid bonds relieve a substantial amount of "I strain" simply by enlarging two of the carbon-carbon bond angles and decreasing the number of hydrogens which generate transannular repulsions.[29] Cyclodecyl tosylate solvolyses in acetic acid have yielded olefins almost exclusively,[23,30] whereas the smaller ring carbonium ions yield substantial amounts of both substitution and elimination products.

Although the addition of chlorine to the cyclodecene (cis and trans) portion of the reaction products has greatly complicated analysis, control experiments have uncovered some information concerning the distribution of the two olefins. The addition of chlorine to cis-cyclodecene in acetic acid produces at least nine products; the major product is believed to be trans-1,2-dichlorocyclodecane (50-60%), which was shown to be the major product from the ionic addition of chlorine to cis-cyclodecene in carbon tetrachloride.[31] Nmr spectral data are consistent with those published by Traynham and Stone.[31] The addition of chlorine to trans-cyclodecene produces at least ten products, no one of which is a major component. Unlike the mixture from ionic addition of chlorine to the trans olefin in carbon tetrachloride, small amounts (5-10%) of trans-1,2-dichloride are apparent in the reaction mixture from the arenesulfenate. Most of these unidentified products, which are believed to be various cis and trans dichlorides, and chloro acetates, are common to both olefins; however, a few minor products are formed from only one olefin or the other. The only statement which can

be made concerning the cis/trans ratio is that in the absence of lithium perchlorate, both olefins are apparent, whereas in the presence of the added salt, the balance apparently shifts, increasing trans-olefin. Perhaps intimate sulfoxonium and/or carbonium ion pairs produce mainly cis-olefin, while solvent-separated ion pairs are largely responsible for trans-olefin.

Completely separated ions have not been considered to be a contributing ionic species in the ionization scheme. Product distribution for the cyclooctyl series has shown no dependence on the presence of lithium chloride, a salt which would cause increase in chloride product via a common ion effect, if completely separated ions were present in the medium. Perhaps acetic acid is not a sufficiently good solvating solvent to enable complete separation of the charged species, in fact, the "Y" value for acetic acid is 1.639;[32] indicating a rather low ionizing power.

After the ion pairing behavior of medium ring carbonium ions, generated from the chlorinolysis of cycloalkyl substrates, had been made apparent, it was believed that transannular hydride shifts occurring in these intermediate cations could be characterized. The use of deuterium labeling in the α position of the starting substrate provides a reference point from which the extent of hydride shift can be determined by nmr analysis. Since deuterium absorptions will not appear in the proton region of the nmr, any observed absorbance for the methine position of substituted chlorinolysis products must be due to hydride shift (see Appendix I).

The results of the chlorinolysis of cyclooctyl-1-d 2,4-dinitrobenzenesulfenate are shown in Table IV. These data indicate that hydride shift occurs to nearly the same extent in intimate and solvent-separated ion pair intermediates. This supports Kwart's hypothesis that no equilibrium exists between carbonium ion pairs.[24] Lithium perchlorate does not affect the extent of hydride shift observed for chloride and acetate. This is to be expected if carbonium ions are not equilibrating, as the perchlorate simply shifts the balance of ion pairs, but does not alter the energy requirements for competing substitution and hydride shifts. If equilibrium between carbonium ion pairs were operating, one would expect the relative scrambling of chloride and acetate to depend on the presence of perchlorate anion. Perchlorate anion could then enhance the proportion of solvent-separated carbonium ion species *via* solvent reorganization of intimate carbonium ion pairs. The lifetime of some solvent-separated carbonium ions would thus be increased and more extensive rearrangement would result with added lithium perchlorate.

The fact that olefin rearrangement *is* dependent on lithium perchlorate is interesting, and suggests that olefin is a product of two different intermediates. The increase in the amount of olefin (dichloride) with added salt indicates that at least part of the olefin is formed by the elimination of solvent-separated ion pairs. The relatively small extent of rearrangement in the olefin when no salt is present is possible evidence for olefin formation *via* a mechanism other than E1. A mechanism which is consistent with the data involves an elimination from an intimate sulfoxonium ion pair in which the chloride ion can abstract a proton. This is reminiscent of elimination from an ion pair in which a gegenion abstracts hydrogen from a diazonium cation[33] (see Scheme III).

TABLE IV

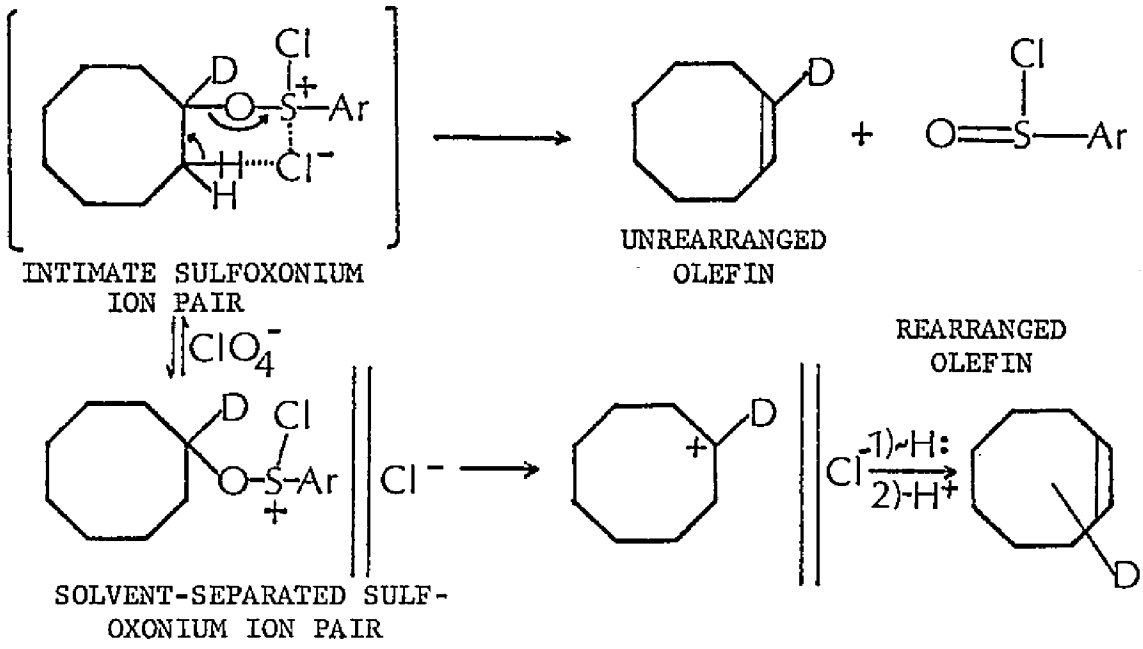
EXTENT OF HYDRIDE SHIFT IN THE CHLORINOLYSIS OF CYCLOOCTYL-1-d 2,4-DINITROBENZENESULFENATE IN ACETIC ACID

RUN	$[LiClO_4]$ (mole/liter)	CHLORIDE	ACETATE	DICHLORIDE*
1	----	44%	---	11%
2	----	45%	---	11%
3	----	42%	50%	9%
4	0.08	---	---	35%
5	0.08	---	---	34%
6	0.08	---	---	35%
7	0.08	42%	50%	34%

*See Appendix I.

SCHEME III

OLEFIN FORMATION IN THE CHLORINOLYSIS OF CYCLOOCTYL ARENESULFENATE



This scheme accounts for limited rearrangement in the absence of lithium perchlorate and more extensive rearrangement when the salt is added. Other mechanisms may also be invoked to account for the dichloride scrambling.

The obvious weakness of the monodeuterated system is its inability to distinguish between transannular and simple 1,2-hydride migrations by nmr analysis. For this reason, the pentadeuterium labeled cyclooctyl and cyclodecyl arenesulfenates (deuterium labels in the β as well as the α positions) were prepared and chlorinated as before. The results of these chlorinolyses are shown in Table V. Again, the extent of hydride shift is essentially the same in the chloride as in the acetate for both ring sizes, and the scrambling in the substitution products shows no dependence on lithium perchlorate. It is apparent that the presence of β deuterium labels allow transannular hydride shifts to occur much more extensively prior to olefin

TABLE V

EXTENT OF TRANSANNULAR HYDRIDE SHIFT IN THE CHLORINOLYSIS OF CYCLOALKYL-d_5 2,4-DINITROBENZENESULFENATES IN ACETIC ACID

ARENESULFENATE	RUN	$[LiClO_4]$ (mole/liter)	CHLORIDE	ACETATE	DICHLORIDE
Cyclooctyl	1	----	39%	44%	---
Cyclooctyl	2	----	39%	41%	29%
Cyclooctyl	3	0.08	45%	45%	63%
Cyclodecyl	4	----	30%	29%	29%
Cyclodecyl	5	----	29%	---	25%
Cyclodecyl	6	0.08	---	---	44%

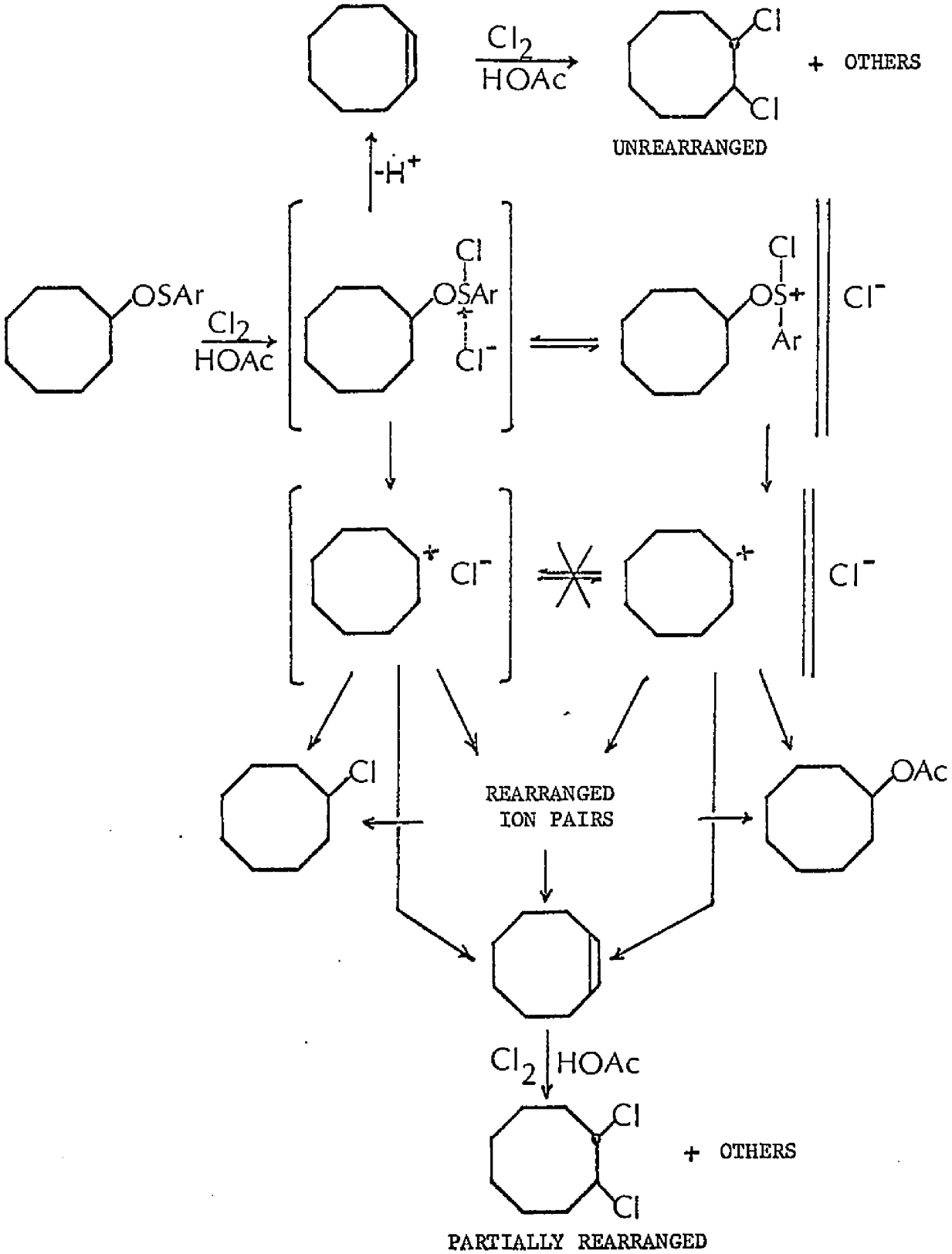
formation. The increase in the extent of rearrangement is a reflection of primary isotope effects which are involved in the elimination of deuterium to form olefin. Deuterium is lost at a slower rate than hydrogen, thus allowing the transannular hydride shift to be a more highly competitive process. Since the initially generated cation reluctantly undergoes elimination of deuterium, there should be a decrease in the amount of olefin produced[34] when there is deuterium in the β positions. This decrease is in fact observed; it amounts to 30-40% with the 8-membered ring, and 20-30% with the 10-membered ring.

The fact that the extent of rearrangement in substitution products is only slightly less for monodeuterated than for pentadeuterated cyclooctyl arenesulfenate chlorinolysis suggests that, at most, only a little 1,2-hydride shift has occurred in unlabeled or monolabeled cyclooctyl cations. However, the isotope effects which are operating here are not fully understood, and firm conclusions concerning 1,2-hydride shifts cannot be made with confidence. It is possible that the presence of β deuterium labels even slows substitution sufficiently to favor the transannular rearrangement. If this be so, more 1,2-hydride shift may be occurring in the unlabeled (or monolabeled) substrate than is readily apparent. A complete ionization sequence for cyclooctyl 2,4-dinitrobenzenesulfenate is shown in Scheme IV.

Bridged carbonium ions, in which participation by transannular hydrogen is involved, are not believed to constitute a significant portion of the intermediates formed in the chlorinolysis of arenesulfenates. Allinger[20] has concluded that such bridged cations are of

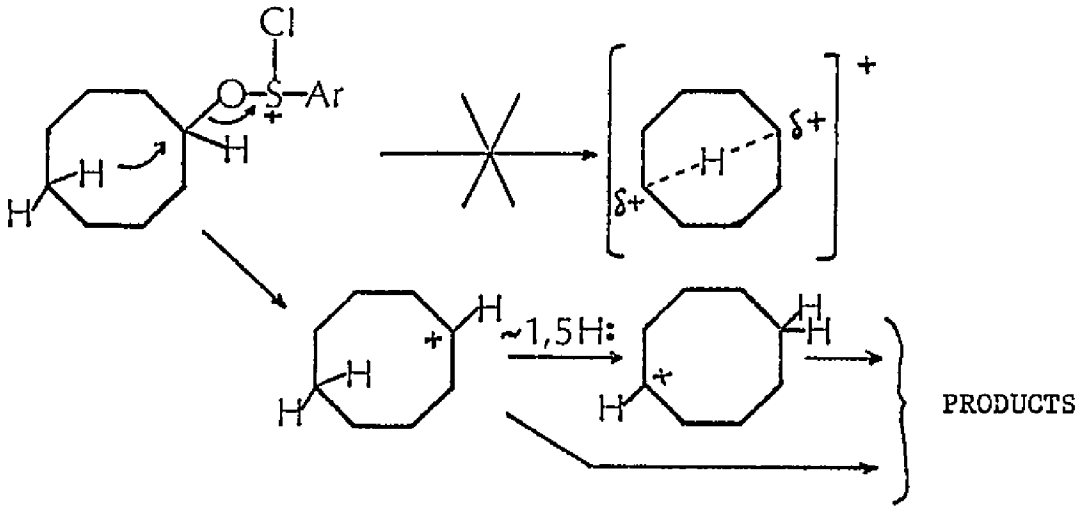
SCHEME IV

TRANSANNULAR HYDRIDE SHIFTS IN CYCLOOCTYL CATIONS



SCHEME V

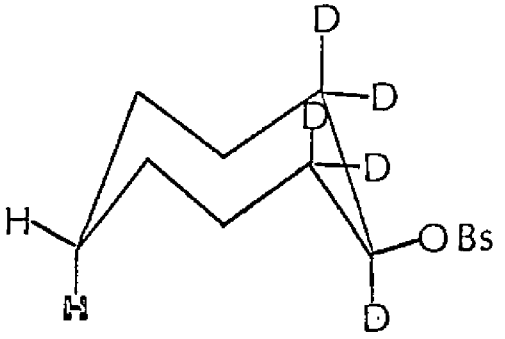
MODES OF TRANSANNULAR HYDRIDE SHIFTS



(other hydride shifts may also occur)

minor importance in the acetolysis of unsubstituted cyclooctyl tosylate. The solvolysis of cis-5-t-butylcyclooctyl tosylate proceeds fifty times faster than that of the corresponding trans isomer and is accompanied by much more rearrangement (see Introduction, page 4). These data present strong evidence for transannular hydrogen participation in the slow step of the reaction of cis substrate. The unsubstituted substrate solvolyzes only twice as fast as the trans isomer, indicating no significant acceleration due to hydrogen bridging in either of these cases. Prelog has excluded bridged cyclodecyl cations as contributing species in tosylate acetolysis also.[10] Although the mechanism of arenesulfenate chlorinolysis does not necessarily parallel that of tosylate solvolysis, the evidence indicates that unsubstituted medium ring carbonium ions undergo hydride shifts from transannular positions to fully developed carbonium ion centers, regenerating a classical ion.

1,5-Hydride shifts have been shown to be the major mode of rearrangement in cyclooctyl-1,2,2,8,8-d_5 brosylate acetolysis, with 1,2- 1,3- and 1,4-hydride shifts not being appreciable.[22] The rationalization for this behavior was made on the basis that the most energetically favored conformation for the unsubstituted cyclooctyl cation, is believed to be a "crown" conformation in which 1,5-hydride shifts occur most easily.



Nmr data indicate that at least the bulk of hydride shift occurring prior to substitution of cyclooctyl cations generated from chlorinolysis is 1,5 in nature. The pentadeuterium scrambled chloride (spectra on page 76) and acetate (spectra on page 77) products show basically the same nmr methine absorption pattern as the unlabeled derivatives. Since 1,4-hydride shifts have been shown to be unlikely,[11] the only transannular hydride shift which will account for forming products whose methine protons are in an environment similar to that of unlabeled products, is 1,5-hydride shift. 1,3-Hydride shift would place the methine proton adjacent to deuterium, decreasing the vicinal hydrogen-hydrogen couplings. This diminished coupling would narrow the methine absorption, an effect which would alter the nmr methine

absorption pattern in such a way as to distinguish it from the pattern for unlabeled products.

The methine multiplet appears to be more well-resolved for the pentadeuterium labeled cyclooctyl products than for the monolabeled or unlabeled cyclooctyl products. The van der Waals radius of deuterium is 0.020 Å smaller than hydrogen,[35] a factor which appreciably decreases the transannular interactions in the medium ring when five deuteriums are present. This decreased strain lowers the energy barrier for conformational changes, thus increasing the rate of ring flipping. The β hydrogens can therefore average more easily on the nmr time scale so that the lines in the methine multiplet sharpen noticeably when the ring has deuterium labels present. When the nmr spectrum is measured at slightly elevated temperature ($\sim 60^{\circ}$), the methine multiplet of scrambled monodeuterium cyclooctyl chloride sharpens to more closely resemble that observed for the scrambled pentadeuterium chloride.

Kwart has shown that some carbonium ions generated from sulfoxonium ions exhibit behavior similar to <u>both</u> decomposition of diazonium ions and the acetolysis of the tosylates.[24] The incompleteness of the data available (see Introduction) limits any comparison of transannular hydride shift among cycloalkyl carbonium ions generated from solvolysis, deamination, or chlorinolysis procedures. Although it appears that less transannular rearrangement occurs in the cyclodecyl cation than in the cyclooctyl cation, additional data are necessary before extensive comparisons can be made.

III. EXPERIMENTAL

A. General

Gas-liquid chromatographic (glc) analyses were carried out on either a Beckman GC-5 or Hewlett-Packard 700 gas chromatograph, both instruments being equipped with hydrogen flame detectors. Columns used included 10' x 1/8", 10% Carbowax 20M, and 6' x 1/8", 10% Ucon UC-W98. Nuclear magnetic resonance (nmr) spectra were obtained from a Varian A-60A nmr spectrometer. Mass spectral (ms) data were recorded by Cheryl White of the Department of Chemistry, Louisiana State University, with a Varian M-66 spectrometer. Infrared (ir) spectra were recorded with a Perkin-Elmer 137 spectrophotometer. Melting points (open capillary) were obtained with a Thomas Hoover melting point apparatus and were corrected. Mr. Ralph Seab of the Department of Chemistry, Louisiana State University, performed all element microanalyses.

B. Preparation of Cycloalkyl 2,4-Dinitrobenzenesulfenates[28]

The procedure[24] for the preparation of cycloalkyl 2,4-dinitrobenzenesulfenates is exemplified by that for cyclooctyl 2,4-dinitrobenzenesulfenate, which is described in detail: 2,4-Dinitrobenzenesulfenyl chloride (Aldrich) was recrystallized from carbon tetrachloride prior to use (mp 95-98°). To a solution of 15.5 g (0.066 mole) of 2,4-dinitrobenzenesulfenyl chloride in 150 ml of 1,2-dichloroethane was added 9.4 g (0.073 mole) of freshly-distilled cyclooctanol (bp 74°, 1.0 mm), followed by 15 ml of pyridine. The mixture was stoppered for two hours before the pyridinium salt was removed by suction filtration. The filtrate was concentrated to an oil by rotary

evaporation, and finally a small amount of water was added to react with excess sulfenyl chloride. The oil was crystallized from ethanol. Cyclooctyl 2,4-dinitrobenzenesulfenate was obtained in 60% yield: mp 100-102°; nmr ($CDCl_3$) δ 9.10 (d,1,J = 2.5 Hz, arom), δ 8.50 (dd,1,J = 9, J′ = 2.5 Hz, arom), δ 7.97 (d,1,J = 9 Hz, arom), δ 3.90 (m,1,J = 6 Hz, CHOSAr), δ 2.05 (m, 4), and δ 1.58 (m, 10). Anal. Calcd for $C_{14}H_{18}N_2O_5S$: C, 51.5; H, 5.6; N, 8.6. Found: C, 51.2; H, 5.5; N, 8.5.

Cyclodecyl 2,4-dinitrobenzenesulfenate, prepared by the same procedure, was obtained in 62% yield: mp 80-82°; nmr ($CDCl_3$) δ 9.07 (d,1,J = 2 Hz, arom), δ 8.51 (dd,1,J = 9, J′ = 2 Hz, arom), δ 8.00 (d,1,J = 9 Hz, arom), δ 4.05 (m,1,J = 6 Hz, CHOSAr), δ 1.97 (m, 4), and δ 1.55 (m, 14). Anal. Calcd for $C_{16}H_{22}N_2O_5S$: C, 54.2; H, 6.3; N, 7.9. Found: C, 54.4; H, 6.4; N, 8.1.

C. Preparation of Cyclodecanone

1. Cyclodecyl chloride[36]

Into a three-neck flask equipped with a condenser, gas dispersion tube, and stopper, and containing 392 g (2.79 moles) of cyclodecane was bubbled 49.7 g (0.7 mole) of chlorine which had previously been dried by passing through concentrated sulfuric acid. The reaction flask was irradiated with an unfrosted 150-watt light bulb, an aluminum foil reflector being situated behind the flask. The contents of the flask were stirred magnetically throughout the course of reaction. After the addition of chlorine was complete (two hours), the stirring was continued for 15 minutes before flushing the system with nitrogen. The cyclodecyl chloride was purified from the excess cyclodecane by

distillation, 71 g (57%) of pure cyclodecyl chloride being collected: bp 70-72° (0.6 mm) [lit[36] 109-110.5° (12 mm)]; nmr (CCl_4) δ 4.23 (p,1,J = 6 Hz, C<u>H</u>Cl), δ 1.95 (m, 4), and δ 1.55 (m, 14).

2. Cyclodecene (<u>cis</u> and <u>trans</u>)

A solution of 70 g (1.25 moles) of potassium hydroxide in 473 ml of ethylene glycol and 55 ml of water was made. The solution was transferred to a three-neck flask equipped with a thermometer, condenser, and stopper, and 96 g (0.55 mole) of cyclodecyl chloride was added. The heterogeneous mixture was heated at 135° for 17 hours while being stirred magnetically. The mixture was cooled and the olefin (top phase) was separated. The ethylene glycol phase (bottom) was poured into an equal volume of water and extracted with two 200-ml portions of pentane. The combined pentane extracts and olefin were washed with water until the washings were neutral to pH paper and then dried over magnesium sulfate ($MgSO_4$). The mixture was concentrated by rotary evaporation, and distillation yielded 40.3 g (53%) of cyclodecenes: bp 62-69° (6.0 mm) [lit[36] <u>cis</u>-cyclodecene: 44-45° (2 mm); <u>trans</u>-cyclodecene: 53-54° (4 mm)]. More severe conditions may have afforded a better yield of olefin, as cyclodecyl chloride was recovered from the distillation pot.

3. Cyclodecanol

Cyclodecanol was prepared following the general procedure for hydroboration.[37] A mixture of <u>cis</u>- and <u>trans</u>-cyclodecene (40.3 g, 0.29 mole) was pipetted into a flame-dried 500 ml, four-neck flask which was being flushed with nitrogen, and 100 ml of dry tetrahydrofuran

(THF) was added. The flask was equipped with a condenser, a thermometer, a nitrogen inlet tube, and an addition funnel which contained 175 ml (0.15 mole) of diborane solution (THF). The mixture was stirred magnetically, chilled to 0° in an ice bath before the diborane was added over a one-hour period, and kept under nitrogen throughout the entire reaction. The solution was allowed to stir for an additional three hours before excess diborane was destroyed by the very slow addition of water. The boron complex was hydrolyzed to the alcohol by the addition of 75 ml of 2 M sodium hydroxide and 40 ml of 30% hydrogen peroxide, and stirring at room temperature for one hour. The contents of the flask were poured into one liter of water and extracted with three 200-ml portions of ether. The combined ether extracts were washed three times with water and then dried ($MgSO_4$). The cyclodecanol solution was concentrated and distilled: bp 93.5-94.5° (1.2 mm), mp 38-41° [lit[38] bp 123-6° (12 mm), mp 42°]. An accurate yield was not determined as the oxidation of the boron complex proceeded inefficiently.

4. Cyclodecanone

Cyclodecanone was prepared by the chromic acid oxidation of cyclodecanol.[39] A solution of 10 g (0.064 mole) of cyclodecanol in 160 ml of acetone was placed in a 250 ml three-neck flask equipped with a condenser, addition funnel, and thermometer. The chromic acid oxidizing agent was prepared by dissolving 8.6 g (0.086 mole) of chromic anhydride (CrO_3) in 16 ml of water followed by 7.5 ml of concentrated sulfuric acid. A small amount of additional water was required to redissolve the salts in the acid solution. The chromic acid was then

transferred to the addition funnel and added dropwise to the rapidly stirred (magnetic) alcohol solution which had been cooled to 0° in an ice bath. Chromium salts had to be removed periodically from the flask to facilitate stirring. After about half of the oxidant had been added, the green reaction solution turned orange. Addition was stopped, and stirring was continued for 15 minutes, as the orange color persisted.

The contents of the reaction vessel were decanted into another flask. The chromium salts were washed with acetone, and the washings were added to the decanted acetone phase. Isopropyl alcohol was added until the orange solution turned green, whereupon 8.1 g (0.095 mole) of sodium bicarbonate was added to the mixture which was stirred until neutral. The contents of the flask were filtered, and the filtrate was concentrated by rotary evaporation until only ketone and water remained. The concentrated mixture was poured into 100 ml of saturated aqueous sodium chloride solution and extracted with two 25-ml portions of ether. The combined ether extracts were washed with water and then dried ($MgSO_4$). Distillation afforded cyclodecanone: bp 66-67° (1.0 mm) [lit[40] bp 99-101° (8 mm)]; nmr ($CDCl_3$) δ 2.56 (m, 4), δ 1.89 (m, 4), and δ 1.41 (m, 10); ir (neat) 5.91 μ (C=O).

D. Deuterium Labeling[22]

1. Monodeuterium Labeled Substrate: Cyclooctyl-1-d 2,4-Dinitrobenzenesulfenate

A stirred suspension of 1.02 g (0.0244 mole) of lithium aluminum deuteride (LAD) in 150 ml of dry ethyl ether was prepared in a flame-dried, 300 ml, three-neck flask equipped with a condenser,

addition funnel, and stopper. A nitrogen atmosphere was maintained in the reaction vessel for the duration of the reduction. A solution of 6.15 g (0.049 mole) of cyclooctanone (Aldrich) in 75 ml of ether was added dropwise to the LAD suspension over a half-hour period. After addition was complete, the mixture was refluxed for 21 hours.

The suspension was hydrolyzed with 100 ml of 3 M hydrochloric acid after the flask had been cooled to 0° in an ice bath. The water layer was extracted with two 25-ml portions of ether, and the extracts were combined with the ether layer. The ether solution was washed first with sodium bicarbonate and then with water before being dried ($MgSO_4$). The ethereal extract was concentrated by rotary evaporation and distilled to give 4.38 g (70%) of the cyclooctanol-1-d: bp 71° (0.9 mm); nmr (CCl_4) δ 3.43 (s,1,CDOH) and δ 1.55 (m, 14).

Cyclooctyl-1-d 2,4-dinitrobenzenesulfenate was prepared in 67% yield: mp 100-102°; nmr ($CDCl_3$) δ 9.08 (d,1,J = 2.5 Hz, arom), δ 8.48 (dd,1,J = 9, J′ = 2.5 Hz, arom) δ 7.95 (d,1,J = 9 Hz, arom), δ 2.00 (m, 4), and δ 1.57 (m, 10). Anal. Calcd for $C_{14}H_{17}DN_2O_5S$: C, 51.4; H (D), 5.8; N, 8.6. Found: C, 51.2; H (D), 5.5; N, 8.6.

2. Pentadeuterium Labeled Substrates

a. Cycloalkanones-d_4

The general procedure for each equilibration was to treat the cycloalkanone (7-15 g) with potassium carbonate (3-6 g) in deuterium oxide (25-75 g) at reflux for three days.[22] After each equilibration, the mixture was cooled and extracted with ether. The ether extracts were dried ($MgSO_4$), concentrated, and either recycled or reduced to the

cycloalkanol-d_5. Only two equilibrations were found to be necessary to replace essentially all of the active methylene hydrogens with deuterium. Two ketones were prepared by this procedure: cyclooctanone-2,2,8,8-d_4, [nmr ($CDCl_3$) δ 1.80 (m) and δ 1.45 (m), no absorption at δ 2.40 (αH); mass spectrum (70 eV) m/e (relative intensity) 130 (93) and 129 (7), which is equivalent to 93% d_4 and 7% d_3 species] and cyclodecanone-2,2,10,10-d_4 [nmr ($CDCl_3$) δ 1.80 (m) and δ 1.36 (m), no absorption at δ 2.55 (αH); mass spectrum (70 eV) m/e (relative intensity) 154 (0), 155 (0.5), 156 (0.5), 157 (3), and 158 (96), which is equivalent to 0.5% d_1 and d_2, 3% d_3, and 96% d_4].

b. Cycloalkyl-d_5 2,4-dinitrobenzenesulfenates

Cycloalkanols-d_5 were prepared by the reduction of the cycloalkanones-d_4 with LAD, as described for cyclooctanol-1-d,[22] and converted to the arenesulfenate as described earlier. The two esters prepared were: cyclooctyl-1,2,2,8,8-d_5 2,4-dinitrobenzenesulfenate [mp 99-102°; nmr ($CDCl_3$) δ 9.08 (d,1,J = 2.5 Hz, arom), δ 8.47 (dd,1,J = 9, J′ = 2.5 Hz, arom), δ 7.95 (d,1,J = 9 Hz arom), and δ 1.58 (m, 10)], and cyclodecyl-1,2,2,10,10-d_5 2,4-dinitrobenzenesulfenate [mp 79-81°; nmr ($CDCl_3$) δ 9.10 (d,1,J = 2 Hz, arom), δ 8.48 (dd,1,J = 9, J′ = 2 Hz, arom), δ 7.97 (d,1,J = 9 Hz, arom), and δ 1.53 (m, 14)].

E. Preparation of Authentic Cycloalkyl Chlorides and Acetates

1. Cyclooctyl chloride

Cyclooctyl chloride was prepared by the addition of hydrogen chloride gas to cyclooctene in the presence of zinc chloride catalyst.[41]

This chloride gave the following data: bp 68-69° (7 mm) [lit[41] bp 87-90° (19 mm)]; nmr (CCl_4) δ 4.15 (m,1,J = 6 Hz, C<u>H</u>Cl), δ 2.05 (m, 4) and δ 1.58 (m, 10).

The preparation of cyclodecyl chloride was described earlier (page 26).

2. Cycloalkyl acetates

Cycloalkyl acetates were prepared by heating the cycloalkanol in acetic anhydride in the presence of sodium acetate overnight. The mixtures were then poured into a relatively large volume of water and extracted with ether. After the extracts had been washed with sodium bicarbonate solution and dried ($MgSO_4$), they were concentrated and distilled under reduced pressure. The acetates prepared were: <u>cyclooctyl acetate</u> [bp 73-75° (1 mm) {lit[42] 95-96° (11 mm)}; nmr (CCl_4) δ 4.84 (m,1,C<u>H</u>OAc), δ 1.91 (s,3,OOCC<u>H</u>$_3$), and δ 1.70 (m, 14)], and <u>cyclodecyl acetate</u> [bp 107-108° (2.5 mm) {lit[42] 120-121° (11 mm)}; nmr ($CDCl_3$) δ 4.15 (m,1,C<u>H</u>OAc), δ 1.99 (s,3,OOCC<u>H</u>$_3$), and δ 1.54 (m, 18)].

F. Chlorinolysis of Cycloalkyl 2,4-Dinitrobenzenesulfenates in Acetic Acid[24]

1. Without Added Lithium Perchlorate

Chlorinolyses of cycloalkyl arenesulfenates followed the general procedure described below for the cyclooctanol derivative. Into a solution of 1 g (0.00306 mole) of cyclooctyl arenesulfenate in 30.6 ml of acetic acid (0.1 <u>M</u> soln.) was bubbled 0.34 ml (0.0075 mole) of dry chlorine through a capillary tube extending beneath the surface of the

acetic acid solution. The chlorine had previously been dried by passing through concentrated sulfuric acid and collected in a tube chilled in a Dry Ice-acetone bath. During the addition of chlorine, which required approximately six minutes, the reaction vessel was maintained at a temperature of $20^{\circ} \pm 1^{\circ}$, and the flask was covered to exclude light. After all of the chlorine had been added, the inlet tube was replaced with a stopper and the reaction mixture was allowed to stir for an additional half hour. When the cover was removed from the flask, it was noted that the intense yellow-orange color of the sulfenate had disappeared and only the yellow-green color of chlorine was apparent. The reaction mixture was then poured into 200 ml of water and extracted with 50 ml of pentane. After the phases had separated, it was noted that a slightly colored solid had formed at the interface. The solid was removed by filtration, and the aqueous layer was extracted twice more with 50-ml portions of pentane. The pentane extracts were combined, washed twice with sodium bicarbonate, and dried ($MgSO_4$). The products were concentrated by rotary evaporation to yield 0.38 g of products. The solid which had separated during the work-up is believed to be 2,4-dinitrobenzenesulfonyl chloride[24] (mp 101-103°) [lit[24] mp 102°]; however, only 0.061 g could be collected as much of it adhered to the glassware.

The products were subjected to glc analysis, and components were identified by the comparison of retention times with those of authentic samples. (Authentic samples were mixed with portions of the product mixture and injected into the gas chromatograph.) Gc area percents were converted to mole percents by the multiplication of appropriate response factors which had previously been determined.

It was necessary to separate the products in pure form for nmr analysis when deuterated arenesulfenates were chlorinated. This separation was accomplished by first distilling and then chromatographing the product mixture on a 2.5 ft alumina column (4% water deactivated). The developing solvents used consisted of pentane/diethyl ether mixtures. The proportion of ether was slowly increased so as to increase the solvent polarity. It was possible to obtain chlorides, acetates, and dichlorides usually in ≥ 99% purity in this manner. Occasionally, microdistillation had to be employed to further purify the samples.

2. With Added Lithium Perchlorate

To a solution of 0.52 g (0.0049 mole) of lithium perchlorate in 61.2 ml of acetic acid (0.08 M soln.) was added 2.0 g (0.00612 mole) of cyclooctyl arenesulfenate. Chlorination was effected as previously described to yield 0.78 g of products. The resulting product distribution of this and another, different run are indicated in Table II.

3. With Added Lithium Chloride

To a solution of 0.13 g (0.00306 mole) of lithium chloride in 30.6 ml of acetic acid (0.1 M soln.) was added 1.0 g (0.00306 mole) of cyclooctyl arenesulfenate. The chlorination was carried out as before. Glc analysis of the resulting product mixture indicated that no appreciable shift in product distribution had occurred.

4. Control Experiments

a. Addition of Chlorine to Cyclooctene in Acetic Acid

To a solution of 0.4 g (0.004 mole) of cyclooctene in 8 ml of dry acetic acid (0.05 M in olefin) was added 0.5 ml (0.011 mole) of dry

chlorine in the manner described for sulfenate ester chlorinolyses. Table VI compares the product distribution obtained here with that from normal sulfenate ester chlorinolysis.

b. Addition of Chlorine to cis- and trans-Cyclodecene in Acetic Acid

The addition of chlorine to cis- and trans-cyclodecenes in acetic acid (0.05 M in olefin) produced at least 13 products which were shown to correspond to the unidentified products in the cyclodecyl arenesulfenate ester chlorinolyses. These are believed to be various dichlorides and chloro acetates which are position and stereoisomers.

TABLE VI

ADDITION OF CHLORINE TO CYCLOOCTENE IN ACETIC ACID[a]

SUBSTRATE	$[LiClO_4]$ (mole/liter)	trans-1,2 DICHLORIDE	-----UNKNOWNS[b]---- A	B	C	D&E[c]
Cyclooctene	----	55	13	6	18	8
Sulfenate Ester[d]	----	52	13	5	21	9
Sulfenate Ester[d]	0.08	50	12	5	24	9

a. Relative gc area percentages are reported here.

b. Believed to be cyclooctyl dichlorides and chloro acetates, lettered in order of increasing retention time on a 6' x 1/8" 10% Ucon UC-W98 column at 160°.

c. These components were not well resolved.

d. Mono-chloride and -acetate products are not included here.

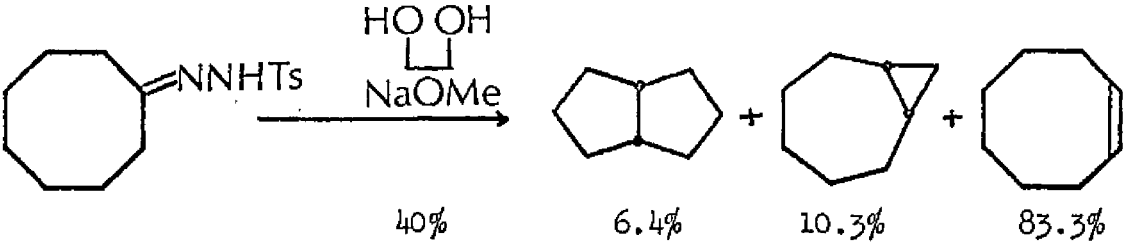
PART TWO

The Generation of Medium Ring Carbonium Ions in Solvents of Low Nucleophilicity: Transannular Eliminations

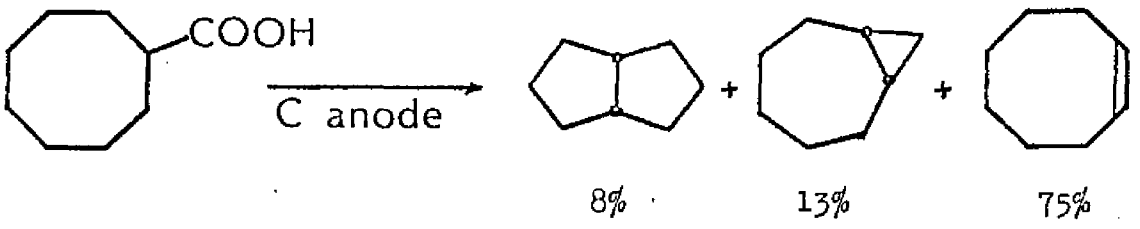
I. INTRODUCTION

It is popular to describe carbonium ions as normal (solvolytic) or "hot" (poorly-solvated) cations[43] whose product analyses are largely a reflection of their different reactivities. Examples of "hot" carbonium ions include those generated from amine deaminations,[44] alcohol deoxideations,[45] and anodic oxidations of carboxylic acids.[46] In each of these reactions, a stable molecule (N_2, CO, or CO_2, respectively) may be lost, with little or no participation by solvent, to form a highly reactive carbonium ion.

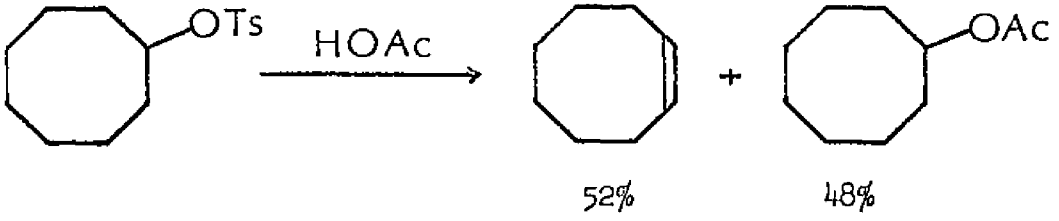
Transannular elimination in medium ring cycloalkyl cations to form bicycloalkanes has been shown to be indicative of these highly energetic intermediates. The decomposition of cyclooctanone tosylhydrazone in ethylene glycol, a reaction which is related to amine deamination, proceeds with the formation of substantial amounts of bicyclooctanes.[47]



Likewise, the anodic oxidation of cyclooctanecarboxylic acid (at a graphite anode) has produced 23% elimination products, including an appreciable quantity of bicyclic hydrocarbons.[48]



These two similar distributions of elimination products can be easily contrasted with that of a typical solvolysis reaction, the acetolysis of cyclooctyl tosylate,[20] in which the only elimination is the normal one to form olefin.



It appears that the pathway to form bicyclooctanes is not open to a "solvolytic" cyclooctyl cation.

In this study, attempts are made to generate solvolytic intermediates which more closely resemble "hot" carbonium ions. Trifluoroacetic acid (TFA)[14] and 2,2,2-trifluoroethanol (TFE)[48] have been shown to be good ionizing solvents of very low nucleophilicity. It was conceived that heterolysis of medium ring substrates in these relatively nonnucleophilic solvents might spawn poorly solvated carbonium ions, whose elimination products might resemble those of tosylhydrazone decompositions and carboxylic acid anodic oxidations.

II. RESULTS AND DISCUSSION

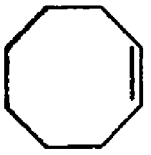
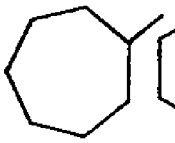
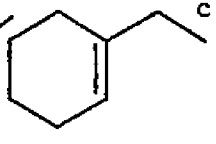
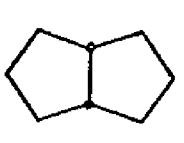
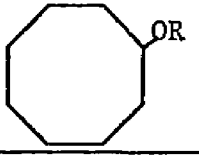
A. Solvolyses of Cyclooctyl Halides

Table VI summarizes the product distribution data obtained for the solvolyses of cyclooctyl halides in various solvents. When conducted for short periods of time, the solvolyses yielded mainly the normal elimination and substitution products. However, when the solvolyses mixtures were heated for extended periods of time, those in TFE and TFA, although not similar to each other, displayed secondary and tertiary product formation not paralleled in the more conventional 80% ethanol/water (EtOH/H_2O) solvent. Furthermore, those products formed in both TFE and TFA included bicyclic and ring-contracted hydrocarbons, rather unusual compounds to be formed in solvolytic reactions.

The fact that chlorocyclooctane solvolysis produces smaller amounts of rearranged products than the bromo derivative (in TFE) is simply a manifestation of the different solubilities of hydrogen bromide and chloride in the reaction medium. Since the solubility of hydrogen bromide (HBr) in water is about three times greater than that of hydrogen chloride (HCl),[49] one would also expect a higher solubility of HBr in TFE. The fact that cyclooctyl bromide apparently solvolyzes more slowly than chloride (see Experimental, C., runs 2 and 3), when the opposite is to be expected,[50] supports this view. Product formation is reversible in the presence of hydrogen halide, the concentration of which determines the extent of return to the starting substrate.

TABLE VII

SOLVOLYSIS OF CYCLOOCTYL HALIDES

RUN	SUBSTRATE	SOLVENT	TEMP.	TIME (hrs)						OTHER
2	bromide	TFE	70°	19	3	3	18	5	--	71[a]
3	chloride	TFE	75°	24[d]	45	---	5	---	41	9[b]
4	bromide	TFA	73°	24[e]	--	3.6[h]	--	0.6[h]	--	96[a]
5	chloride	TFA	73°	24[e]	--	3.6[h]	--	0.6[h]	--	96[a]
6	bromide	80% $\frac{EtOH}{H_2O}$	80-5°	18	53	0	0	0	46[f]	0
7	bromide	80% $\frac{EtOH}{H_2O}$	70°	71	0	0	0	0	43[g]	57

a. A wide variety of volatile products plus some polymer constituted this mixture.

b. These were the same unidentified products formed in run 2 at short reaction times.

c. Ethylidenecyclohexane was also present, and is included below.

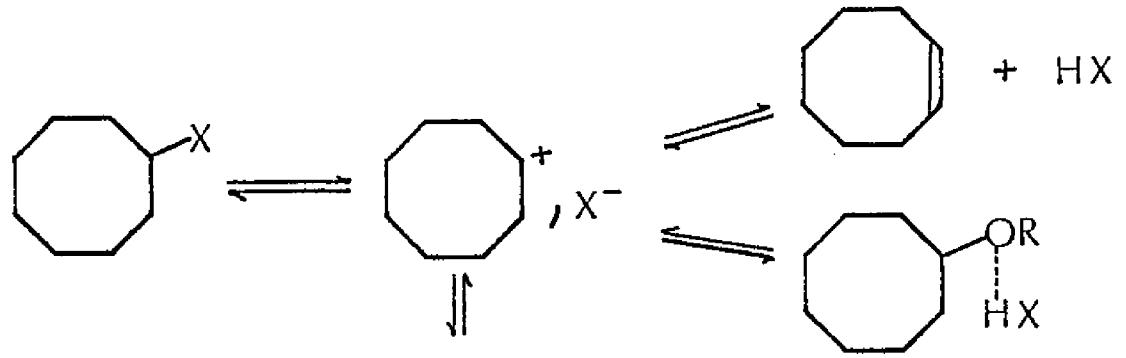
d. This reaction (primary and secondary) was essentially complete after 11 hours.

e. Starting bromide had disappeared in 1-1/4 hours.

f. This datum represents 23% ether and 23% alcohol product.

g. This datum represents 23% ether and 20% alcohol.

h. These percentages were determined by standard addition of pure hydrocarbons.



The more soluble HBr (also stronger acid) will enhance the reverse reaction, accounting for the "apparent" slowness of bromide disappearance, and also the increased extent of rearrangement, relative to chloride substrate. Lack of dependence on leaving group for solvolyses conducted in TFA (Table VII, runs 4 and 5), which is itself a strong acid, further supports these conclusions.

That the products formed in TFE and TFA are different from those formed in 80% EtOH/H_2O, is a reflection of the nature of the solvents themselves, and not only of the acid concentration. The dielectric constants of TFE (26.14 at 25°)[51] and TFA (8.42 at 20°)[52] are lower than that for 80% EtOH/H_2O [34.1 at 25°, extrapolated for 80% (v/v) from 80% (wt/wt)],[53] an indication that hydrogen halide solubility in the latter solvent should be adequate to catalyze secondary (and tertiary) product formation if the role of the solvent were unimportant. Since only normal elimination and substitution products are observed for solvolyses conducted over extended reaction times in 80% EtOH/H_2O (Table VII, run 7), the evidence appears to be conclusive that TFE and TFA do not stabilize intermediate carbonium ions as well as the more nucleophilic solvent. This diminished solvation increases the energy of the

carbonium ion sufficiently so that product pathways, not usually available to solvolytic, medium ring carbonium ions, present themselves.

Although the distribution of products generated in TFE and TFA solvents are complex, a surprising discovery was made during the investigation of control experiments. When bicyclo[5.1.0]octane is either solvolyzed in TFA or protonated with HBR in TFE, the resulting product mixture matches remarkably those obtained from solvolysis of cyclooctane derivatives under the same conditions. One or both of the following may account for these observations: (1) Both bicyclo[5.1.0]-octane and cyclooctyl halides form the same reaction intermediate(s) in a given solvent; or (2) bicyclo[5.1.0]octane is a product of solvolyses in TFE and TFA and, in the presence of strong acid (HX in the former case, and solvent in the latter), is protonated and forms new products, including six- and seven-membered ring substituted hydrocarbons.

Another interesting feature of these solvolyses is the presence of substantial amounts of 1-ethylcyclohexene and ethylidenecyclohexane in TFE solvolyses mixtures (olefins are easily protonated in TFA). Olah[54] has recently shown that the cyclooctyl cation, when generated in a medium of very low nucleophilicity (SbF_5-SO_2ClF), rearranges to the 1-ethylcyclohexyl cation. The driving force for this rearrangement is the relief of steric strain as well as the formation of a tertiary carbonium ion. The 1-ethylcyclohexyl cation has also been shown to arise from the rearrangement of the 1-methylcycloheptyl cation in the same medium.[54] The low nucleophilicity of the TFE medium appears to be responsible for extensive skeletal rearrangement of the cyclooctyl cation which is formed either by heterolysis of starting

halide or reversal of normal elimination and substitution steps. A non-classical, edge protonated, cyclopropane carbonium ion cannot be excluded as a possible intermediate. Such a carbonium ion would eliminate the necessity of going through a primary carbonium ion, a highly unlikely process, in the ring contraction process.[55] Scheme VI shows several different ionic intermediates which may be present in the TFE and TFA media.

B. Solvolyses of Cyclodecyl Halides

Table VIII summarizes the product distribution data obtained for the solvolyses of cyclodecyl halides in various solvents. Unlike the cyclooctyl halide solvolyses, secondary product formation (in TFE and TFA solvents) was greatly simplified. Substantial amounts of cis- and trans-decalin were formed in both solvent systems. Again, the extent of product formation in TFE depends on leaving group, whereas TFA solvolyses show no such dependence. The same arguments put forth in Section A may be invoked to rationalize this behavior. Decalin is apparently the only stable, volatile product which is formed in the acidic media, as the proportion was found to increase at the expense of all other components of the mixture (in TFE, olefin was the only other observed component besides starting bromide). Scheme VII is a representation of the different product-forming steps which occur in the solvolysis of cyclodecyl halides. As in the cyclooctane series, normal solvolysis products formed in 80% EtOH/H_2O do not compare to those generated in the poorly nucleophilic TFA and TFE media.

SCHEME VI

THE IONIZATION OF CYCLOOCTYL HALIDES IN SOLVENTS OF LOW NUCLEOPHILICITY

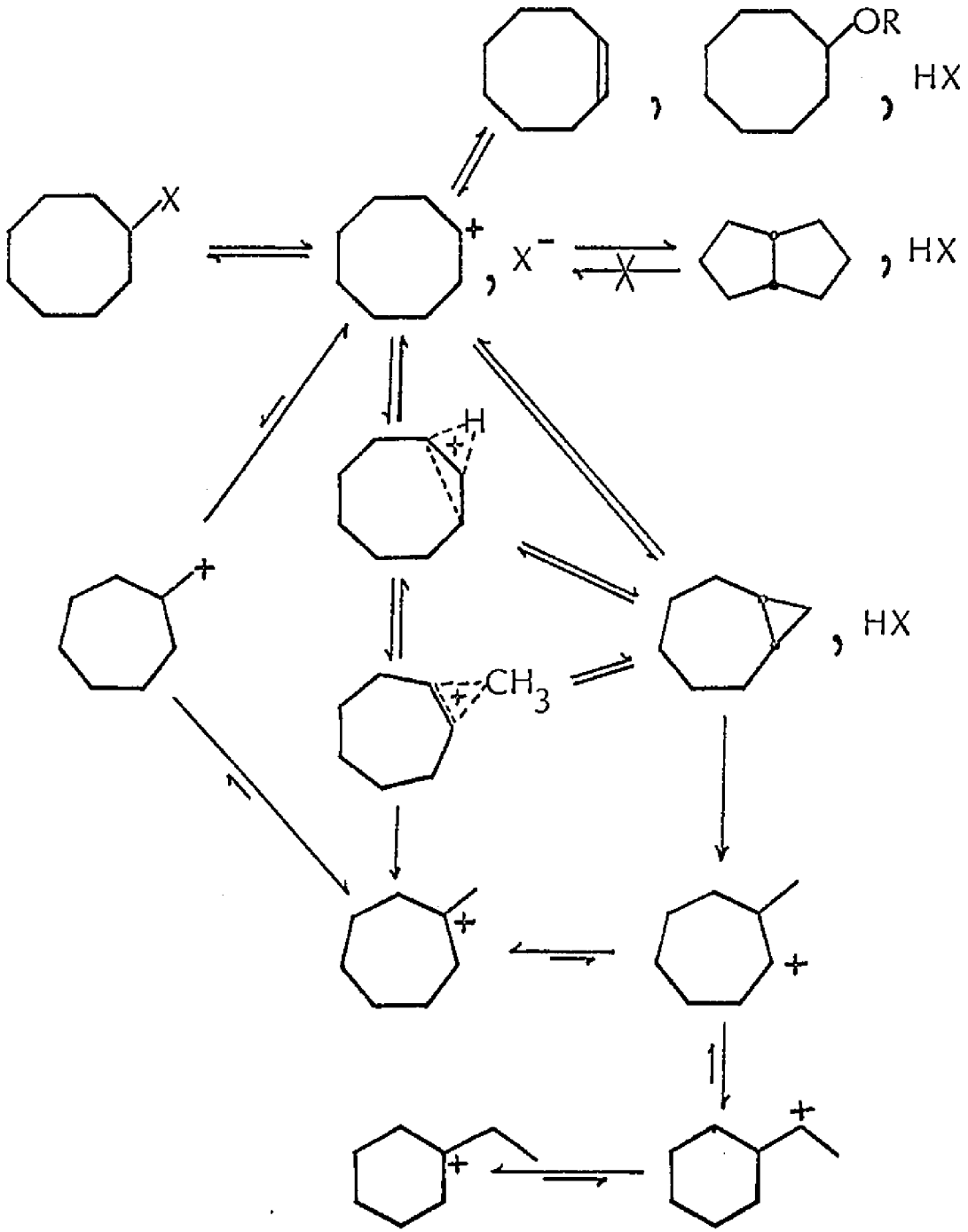
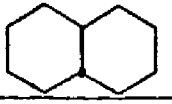
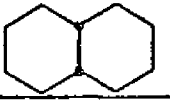
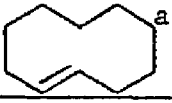
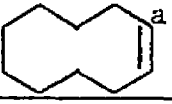


TABLE VIII

SOLVOLYSIS OF CYCLODECYL HALIDES

RUN	SUBSTRATE	SOLVENT	TEMP.	TIME (hrs)			 [a]	 [a]		OTHER
8	chloride	TFE	75°	17[b]	3	2	5	82	6	1[c]
9	chloride	TFE	75°	72[b]	3	2.5	3.5	87	4	0
11	bromide	TFE	75°	48	36	30	0	30	trace	4[d]
12	chloride	TFA	73°	37[e]	16[f]	10[f]	0	1[f]	-------	73[g]
13	bromide	TFA	73°	37[e]	16[f]	10[f]	0	1[f]	-------	73[g]
14[h]	chloride	80% $\frac{EtOH}{H_2O}$	80-5°	72	0	0	78	18	≤ trace	4[d]

a. Control experiments (see Experimental) have shown that acid catalyzed trans → cis isomerization occurs rapidly in TFE and TFA.

b. These reactions were essentially complete after 3-1/4 hours.

c. Unidentified material.

d. Unreacted starting material.

e. The primary reaction was complete in 10 minutes.

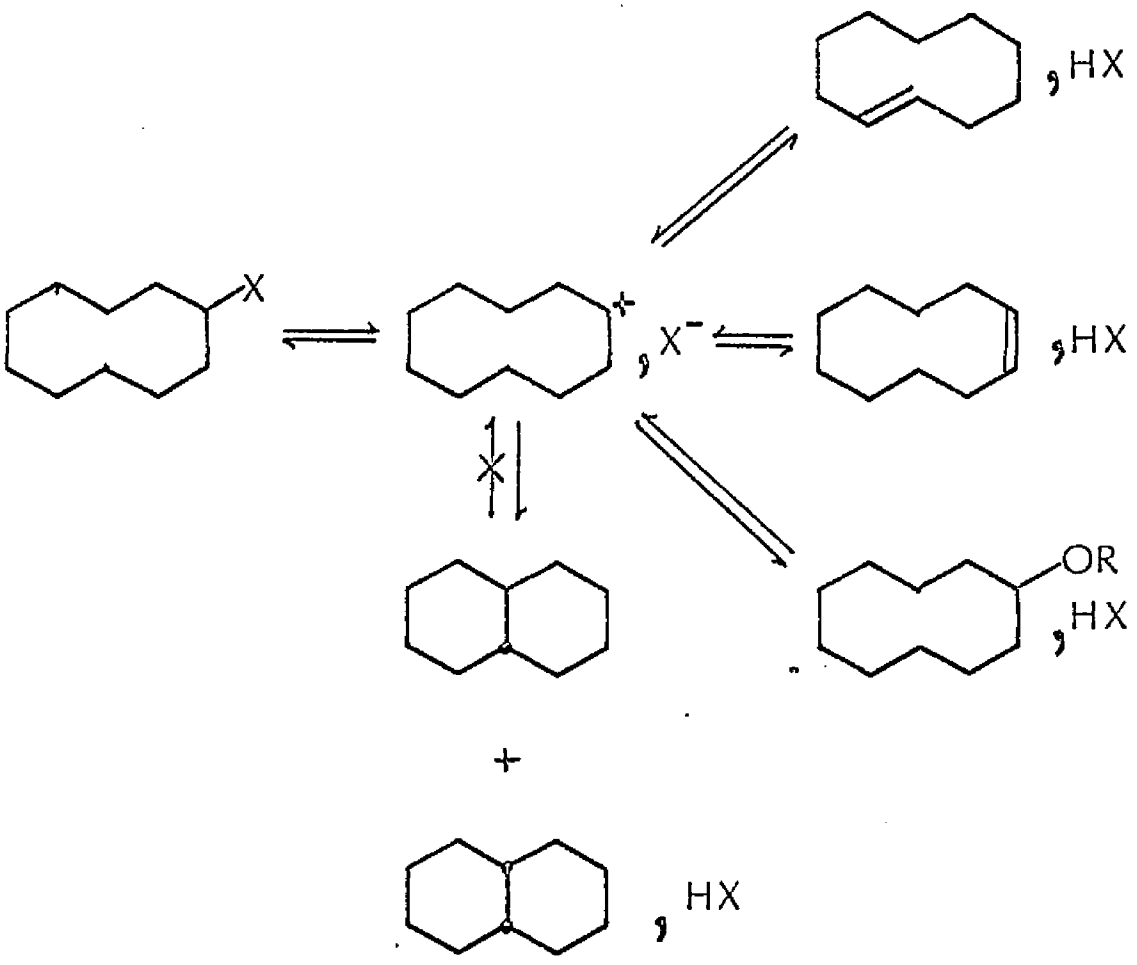
f. These hydrocarbons were separated from the reaction mixture (i.e., lower limit on yield).

g. Mostly polymer

h. The product mixture was unchanged after 2 weeks.

SCHEME VII

THE IONIZATION OF CYCLODECYL HALIDES IN SOLVENTS OF LOW NUCLEOPHILICITY



It would appear that solvolyses in TFE or TFA produce mainly cis-cyclodecene, while those in 80% $EtOH/H_2O$ and acetic acid[22] produce mainly trans-cyclodecene. Control experiments have shown, however, that trans-cyclodecene isomerizes to the thermodynamically more stable cis-cyclodecene rapidly in TFE (acid catalyzed).

III. CONCLUSIONS

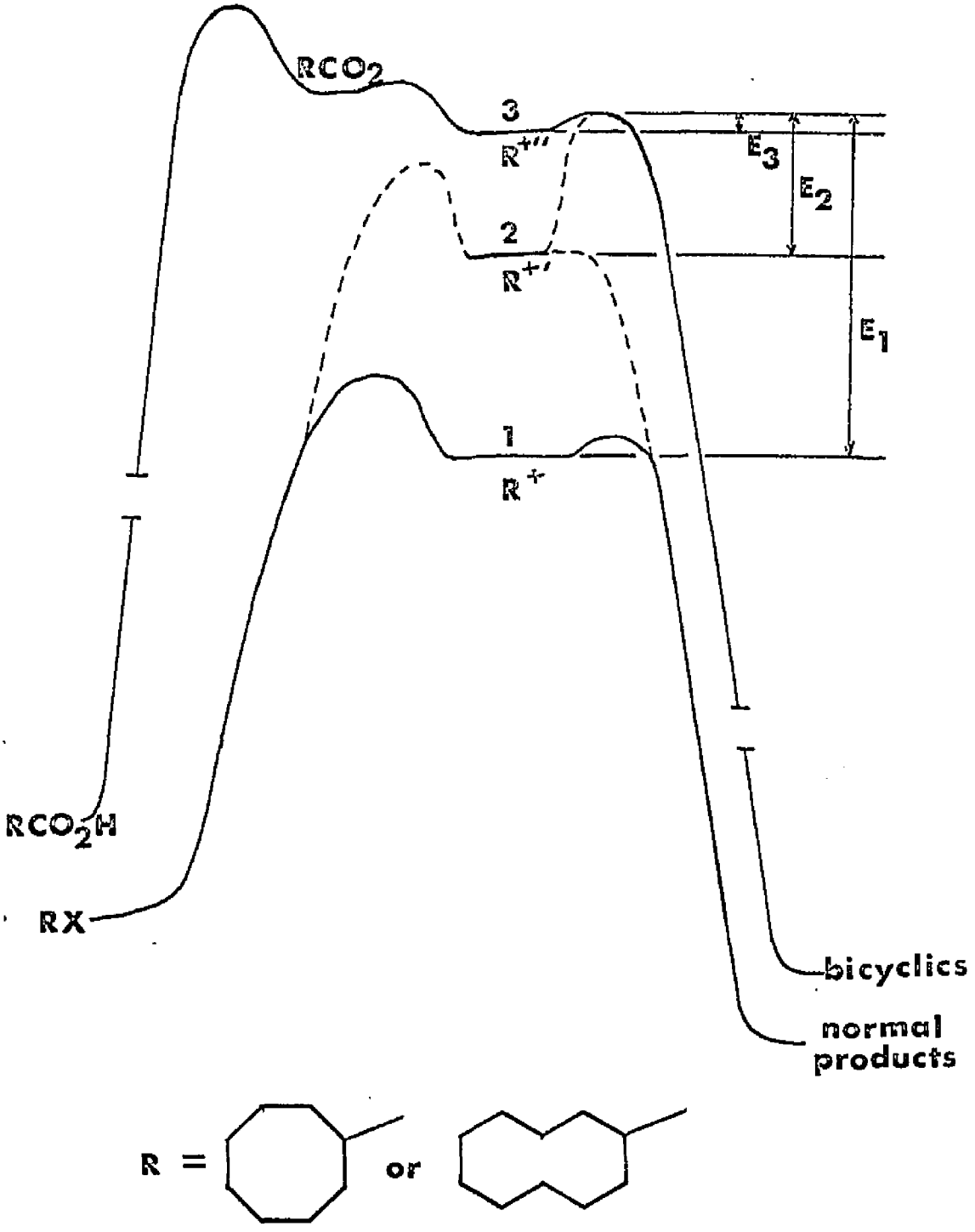
A likely representation of reaction coordinates for carbonium ions of different energies is shown in Figure 1. The energy of a "hot" carbonium ion (level 3) is relatively high and may easily surmount the barrier (E_3) to form bicyclic hydrocarbons as well as the normal products (olefin and substitution products). A "normal" carbonium ion (level 1) cannot overcome the tremendous barrier (E_1) to form transannular elimination products, but instead produces the expected monocyclic compounds. Solvolytic carbonium ions which are not stabilized greatly by solvent, such as those generated in TFE and TFA, will have an energy somewhere between levels 1 and 3 (level 2). The energy barrier (E_2) to form bicyclic hydrocarbons may still be high, but the reversibility of normal product formation increases the probability that an appreciable quantity of cycloalkyl cations make it over the "hump".

The diagnostic hydrocarbons produced in those reactions commonly believed to involve "hot" carbonium ion intermediates consist of bicyclo[x.1.0]- and bicyclo[y.3.0]alkanes. The absence of bicyclo-[5.1.0]octane in TFE and TFA solvolysis mixtures from cyclooctyl halides can be attributed to the instability of this compound in strong acid media. Control experiments indicate that substantial quantities of this bicycloalkane may be formed in the early stages of reaction. Bicyclo[4.4.0]decane (decalin) rather than bicyclo[5.3.0]-decane is formed in TFE and TFA solvolyses. This difference from the corresponding carboxylic acid anodic oxidation may simply be a reflection of minor conformational differences between the two reaction intermediates.

FIGURE 1

REACTION COORDINATES FOR MEDIUM RING

CARBONIUM IONS FROM DIFFERENT PRECURSORS



Since transannular elimination is a common primary process for some reactions,[46,47] substantial in TFE and TFA solvolyses (secondary product formation), and not at all observed in more nucleophilic solvolyses (80% EtOH/H_2O), it appears that the division of carbonium ion reactivities into "hot" and "normal" is not sufficient. The carbonium ions generated in TFE and TFA solvolyses might then be described as "warm", in which case it becomes obvious that the boundaries separating these cations into classes are ill defined and in many cases should be reinvestigated.

IV. EXPERIMENTAL

A. General

The analytical techniques employed were for the most part the same as those described in "Part One" (Experimental). All solvolysis reactions were conducted by simply dissolving the cycloalkyl halide in the solvent (usually agitated during warming to facilitate solution), and heating, usually at reflux. Many reactions were monitored by withdrawing aliquots with a hypodermic syringe (the reaction flask being equipped with a septum-capped side-arm) and injecting the sample directly into a gc instrument. TFE mixtures were extracted with pentane to remove products (TFE was distilled and reused), whereas all other mixtures were poured into water and extracted with pentane or ether. Extracts were usually washed with sodium bicarbonate solution and dried ($MgSO_4$) prior to analysis.

Product distribution data were often obtained from gc data which were supplemented with nmr data (for molar ratios of compounds which were not isomeric). Occasionally, product distributions were simplified (e.g., by distillation or chromatography) in order to make glc a better measure of product distributions. The standard addition technique was also employed to determine the mole content for certain components in some reaction mixtures. Identifications were made on the basis of glc retention times (authentic samples were added to portions of the mixture and relative changes in distribution were noted) and nmr analysis of pure components. Many of the solvolytic runs reported are representative of more than one run.

B. Preparation of Cycloalkyl Bromides

Cyclooctyl and cyclodecyl bromides were prepared following the general procedure for cyclooctyl bromide.[56] Hydrogen bromide gas (54 g, 0.67 mole) was bubbled into an Erlenmeyer flask containing 200 ml of acetic acid. To this solution was added 39 g (0.355 mole) of cyclooctene. The mixture was stirred vigorously with a magnetic stirrer at room temperature over a week-end before the contents of the flask were poured into a separatory funnel containing 700 ml of water. The water phase was extracted with 200 ml of ether. The ether extract was dried ($MgSO_4$) and concentrated by rotary evaporation.

Distillation yielded 55.5 g (82%) of cyclooctyl bromide: bp 56-56.8° (0.6 mm) [lit[56] bp 90.5-91.5° (10 mm)]; nmr (neat) δ 4.37 M,1,J = 6 Hz, CHBr), δ 2.20 (m,~4), and δ 1.60 (m,~10).

In a similar fashion, cyclodecyl bromide was prepared from cyclodecene (a mixture of cis and trans). Distillation yielded 12.4 g (74%) of cyclodecyl bromide: bp 91-92° (1.3 mm) [lit[57] bp 128° (14 mm)]; nmr ($CDCl_3$) δ 4.46 (p,1,J = 6 Hz, CHBr), δ 2.10 (m,~4) and δ 1.53 (m,~14).

C. Solvolysis of Cyclooctyl Halides

1. Solvolysis of Cyclooctyl Bromide in TFE

Run 1: Cyclooctyl bromide (7.5 g, 0.0392 mole) was dissolved in 147 ml (0.27 M in bromide) of TFE and heated at 75° for 12 hours. The products were introduced into a 2' alumina column and eluted in sequence with 250 ml of pentane; 250 ml of 4:1, pentane:ethyl ether; 200 ml of ethyl ether; 75 ml of 1:1, ethyl ether:methanol; and finally 125 ml of methanol. The first cuts (which eluted in pentane) were

combined to yield 2.44 g. This mixture was partially distilled to yield 0.78 g of volative products consisting of one major component (70-80%). The bulk of the pot residue consisted of high-boiling material. Two of the minor components were shown to be methylcycloheptane and bicyclo[3.3.0]octane. Preparative glc (10' x 2/8", 10% Carbowax 20 M) was employed to obtain a pure sample of the major product in the distillate. The nmr spectrum agreed exactly with that obtained for the mixture of isomeric olefins formed in the dehydration of 1-ethylcyclohexanol (i.e., ethylidenecyclohexane and 1-ethylcyclohexane; see page 63).

Run 2: Cyclooctyl bromide (0.8067 g, 0.00422 mole) was dissolved in 21 ml (0.2 M in bromide) of TFE and heated at 75° for 19 hours. Aliquots of the reaction mixture indicated that cyclooctene and cyclooctyl trifluoroethyl ether were the only detectable products initially formed. However, both of these primary products decreased with time as 1-ethylcyclohexene (and ethylidenecyclohexane) and other secondary products became increasingly evident. Most of the starting bromide (> 95%) had disappeared after 19 hours, leaving a very complex mixture of products.

The mixture was chromatographed on a 1.5' alumina column, eluted with pentane. The initial cuts were combined to yield 0.17 g of material whose glc product distributions (area percent) consisted of the following: 1-ethylcyclohexene and ethylidenecyclohexane (48%), bicyclo[3.3.0]octane (14%), methylcycloheptane (7%), cyclooctene (7%), and six unidentified components (24%). In other runs with longer reaction times, it was noted that many of the volatile products, including

the above olefins, disappeared from the reaction mixture. Apparently, polymerization occurred in the presence of the strong acid, HBr.

2. Solvolysis of Cyclooctyl Chloride in TFE

Run 3: Cyclooctyl chloride (0.75 g, 0.051 mole) was dissolved in 25.5 ml (0.2 M in chloride) of TFE and heated at 75° for 24 hours. Glc analysis of aliquots of the reaction mixture revealed that nearly all of the chloride had reacted after 11 hours; however, reaction was continued for 24 hours. The normal elimination and substitution products, which were immediately apparent at the start of reaction, continued to increase up to 11 hours. The unidentified products were shown to be the same as those formed in the bromide solvolysis. However, no substantial increase was noted after 11 hours, the product distribution remaining essentially constant up to 24 hours. Combined nmr and glc data determined the following product distribution: cyclooctene (45%), cyclooctyl trifluoroethyl ether (41%), ethylidenecyclohexane and 1-ethylcyclohexene (5%), unidentified (9%). (The glc chromatogram of chloride solvolysis products after 11 hours appeared to be very similar to that of bromide solvolysis after 30-40 minutes.)

3. Solvolysis of Cyclooctyl Bromide in TFA

Run 4: Cyclooctyl bromide (2.76 g, 0.0144 mole) was dissolved in 72 ml (0.2 M in bromide) of TFA and heated at 73° for 24 hours. Bromide disappeared from the reaction mixture in 1.25 hours, cyclooctyl trifluoroacetate being the main product initially formed. As the reaction was allowed to continue, secondary product formation became evident as the trifluoroacetate decreased and other products appeared.

The reaction was stopped after most of the trifluoroacetate had disappeared from the medium (24 hours). After work-up, standard addition of methylcycloheptane was made to the mixture in order to determine the amount of that cyclic hydrocarbon present; 5.2×10^{-4} mole (3.6%) of methylcycloheptane had been formed in the solvolysis. Also identified was bicyclo[3.3.0]octane (0.6%). The product mixture was extremely complex, glc revealing the presence of 25 volatile components.

4. Solvolysis of Cyclooctyl Chloride in TFA

Run 5: Cyclooctyl chloride (0.763 g, 0.0052 mole) was dissolved in 26 ml (0.2 M in chloride) of TFA and heated at 73° for 24 hours. The glc chromatogram of products almost exactly matched that from the bromide solvolysis in TFA.

5. Solvolysis of Cyclooctyl Bromide in 80% EtOH/H_2O

Run 6: Cyclooctyl bromide (1.056 g, 0.00553 mole) was dissolved in 25 ml (0.22 M in bromide) of 80% EtOH/H_2O (v/v) and heated at 80-85° for 18 hours. Glc analysis showed that only three products had formed. Cyclooctene and cyclooctanol were identified by the addition of authentic samples to the reaction mixture and subsequent glc analysis. The other product, believed to be the ether, was indicated by the nmr spectrum (signals for -O-$C\underline{H}_2$-$C\underline{H}_3$). Nmr spectra were used to determine the product distribution: cyclooctene (53%), cyclooctyl ethyl ether (23%), and cyclooctanol (23%).

Run 7: Cyclooctyl bromide (11.8 g, 0.0618 mole) was dissolved in 125 ml (0.5 M in bromide) 80% EtOH/H_2O (v/v) and heated at 75° for 71 hours. Glc analysis revealed the same three products as in Run 7,

(no bicyclics or ring contraction products evident) and nmr spectra revealed the following distribution: cyclooctene (57%), cyclooctyl ethyl ether (23%), and cyclooctanol (20%).

D. Solvolysis of Cyclodecyl Halides

1. Solvolysis of Cyclodecyl Chloride in TFE

Run 8: Cyclodecyl chloride (1.1480 g, 0.00657 mole) was dissolved in 24 ml (0.27 M in chloride) of TFE and heated at 75° for 17 hours. Glc analysis demonstrated the presence of cis- and trans-decalin and cis- and trans-cyclodecene. Two other components were present, the major one believed to be the trifluoroethyl ether, as the nmr spectrum of the mixture displayed a characteristic quartet for the O-CH_2-CF_3 absorption. Combined glc and nmr analyses revealed the following product distribution (weight of products = 0.84 g): trans-decalin (3%), cis-decalin (2%), trans-cyclodecene (5%), cis-cyclodecene (82%), cyclodecyl trifluoroethyl ether (6%), and unidentified material (1%).

Run 9: Cyclodecyl chloride (1.06 g, 0.00605 mole) was dissolved in 22 ml (0.27 M in chloride) of TFE and heated at 75° for 3 days. Glc and nmr analysis revealed essentially the same distribution as in Run 8: trans-decalin (3%), cis-decalin (2.5%), trans-cyclodecene (3.5%), cis-cyclodecene (87%), and cyclodecyl trifluoroethyl ether (4%).

Run 10: Cyclodecyl chloride (0.884 g, 0.00502 mole) was dissolved in 25 ml (0.2 M in chloride) of TFE and heated at 75° for 3.25 hours. The variation of trans-olefin/cis-olefin ratio with time was the major concern in this experiment. The data are summarized in the following table.

Time (hrs)	trans-Olefin/ cis-Olefin	Chloride
0.08	63/37	large amount
0.58	28/72	substantial amount
2.75	7/93	small amount
3.25	5/95	2% (ca.)

2. Solvolysis of Cyclodecyl Bromide in TFE

Run 11: Cyclodecyl bromide (0.797 g, 0.00363 mole) was dissolved in 18.2 ml (0.2 M in bromide) of TFE and heated at 75° for 48 hours. Aliquots of the reaction mixture were analyzed by glc at regular intervals. Besides olefins, decalin appeared in the mixture after 0.5 hour and increased with time while the olefin (cis-cyclodecene) decreased. After 48 hours, some bromide was still present. The glc product distribution was as follows: trans-decalin (36%), cis-decalin (30%), cis-cyclodecene (30%), and cyclodecyl bromide (4%).

3. Solvolysis of Cyclodecyl Chloride in TFA

Run 12: Cyclodecyl chloride (3.0 g, 0.0171 mole) was dissolved in 85.5 ml (0.2 M in chloride) of TFA and heated at 73° for 37 hours. Glc analysis of an aliquot from an earlier run indicated that the chloride had all reacted in 10 minutes. However, cyclodecyl trifluoroacetate, the initially formed product, decreased with time while decalin increased. The above reaction mixture, after work-up, was chromatographed on a 2' alumina column (4% water deactivated), being eluted with pentane. The first cuts, which contained decalin, a small amount of olefin, and polymer, were distilled, yielding 0.64 g (0.0047 mole)

of hydrocarbon products, bp 60-62° (8 mm). Glc analysis determined the distribution as: trans-decalin (59%), cis-decalin (37%), and cis-cyclodecene (2%). On the basis of starting bromide, this mixture constituted 27% of the material balance. The remainder of the products consisted mostly of polymer and minor amounts of unidentified volatile material.

4. Solvolysis of Cyclodecyl Bromide in TFA

Run 13: Cyclodecyl bromide (0.767 g, 0.0035 mole) was dissolved in 17.5 ml (0.2 M in bromide) of TFA and heated at 73° for 37 hours. After work-up, glc analysis revealed that cyclodecyl bromide produced the same product distribution as had the chloride (Run 12).

5. Solvolysis of Cyclodecyl Chloride in 80% EtOH/H_2O

Run 14: Cyclodecyl chloride (1.11 g, 0.0635 mole) was dissolved in 32 ml (0.2 M in chloride) of 80% EtOH/H_2O (v/v) and heated at 80-5° for 3 days. Glc analysis revealed the following distribution: trans-cyclodecene (78%), cis-cyclodecene (18%), and cyclodecyl chloride (4%). No decalin was apparent. The product mixture showed no appreciable change during two weeks reaction time.

E. Preparation of Various Authentic Samples for GLC Analyses

1. Bicyclo[x.y.0]octanes

a. p-Toluenesulfonohydrazide[58]

p-Toluenesulfonyl chloride (39.6 g, 0.208 mole) was dissolved in 100 ml of benzene. While the benzene solution was being stirred magnetically in an ice bath, 23 ml of 85% hydrazine hydrate (0.4 mole)

was added dropwise. The tosylhydrazide* formed rapidly, and stirring became difficult. After the reaction mixture had stood for two hours, the tosylhydrazide was filtered with suction. The product was washed first with 100 ml of cold water and then with 60 ml of pentane. After drying, the tosylhydrazide was recrystallized rapidly from 15 parts of water to yield 26.3 g (68%) of product, mp 109-110° [lit[58] mp 112°].

b. Cyclooctanone tosylhydrazone[47]

A solution of 7.68 g (0.06 mole) of cyclooctanone and 11.2 g (0.06 mole) of tosylhydrazide in 40 ml of absolute ethanol was refluxed for one hour. After the reaction mixture had cooled, 16.1 g (91%) of cyclooctanone tosylhydrazone was removed by filtration and washed with cold ethanol; mp 142-145° (uncorrected) [lit[59] mp 140-141°].

c. Decomposition of Cyclooctanone Tosylhydrazone in an Aprotic Solvent[47]

A stirred suspension of 14.7 g (0.27 mole) of sodium methoxide and 16.1 g (0.055 mole) of cyclooctanone tosylhydrazone in 150 ml of diethyl Carbitol was heated at 165-170° for two hours. The mixture was distilled slowly, and the distillate was added to 100 ml of pentane. The pentane solution was washed with two liters of water, then with smaller portions (eight times) to remove diethyl Carbitol. It was dried ($MgSO_4$) overnight. The pentane solution was distilled, and the hydrocarbon products were collected at 65° (65 mm). The yield, which appeared to be lower than expected, may have been affected by slightly wet solvent or sodium methoxide.

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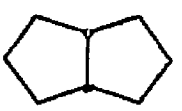
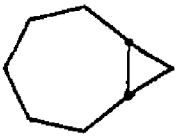
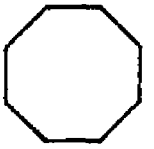
*"Tosyl" is the common designation for p-toluenesulfono derivatives.

Distribution of Transannular Carbene Insertion Products

Reference			
this work	49	14	37
47	50	7	43
59	46	9	45

The above mixture was used for identification purposes.

2. Methylcycloheptane

a. 1-Methylcycloheptene

Dry magnesium turnings (2.57 g, 0.106 g. atom) and 10 ml of dry ether were placed into a three-neck, flame-dried flask equipped with a condenser, addition funnel, and stopper. A solution of 14.2 g (0.10 mole) of methyl iodide in 20 ml of ether was added dropwise to the contents of the flask which were stirred magnetically. After the reaction had subsided, 11.2 g (0.10 mole) of cycloheptanone in 15 ml of ether was added to the Grignard reagent slowly at room temperature, then the mixture was refluxed for one hour. The reaction mixture was hydrolyzed with 3M hydrochloric acid. The ether phase was concentrated, oxalic acid (5 g) was added, and the mixture was distilled at atmospheric pressure. As expected, two phases (olefin and water) appeared in the distillate initially (bp 94°) before dry olefin was collected: bp 133-137° [lit[60] bp 137.5-138.5°]. An nmr spectrum showed two vinyl absorptions centered at δ 5.55 (broadened triplet) and δ 4.68 (sharp multiplet), in a ratio of about 10:1. The predominant olefin was shown to be methylcycloheptene, by comparison with the nmr spectrum of an

authentic sample (Aldrich). The minor olefin product was believed to be methylenecycloheptane. This mixture of olefins was used directly in the hydrogenation step described below.

b. Methylcycloheptane

A solution of 2.0 g (0.018 mole) of 1-methylcycloheptene in 26 ml of methanol was placed into a 500 ml pressure bottle containing 0.5 g of 5% palladium on carbon (50% water wet). The contents of the bottle were thoroughly flushed with nitrogen to remove the oxygen before the bottle was placed into a Paar low pressure hydrogenator. The system was then flushed several times with hydrogen before shaking was commenced at a pressure of 50 p.s.i. After the pressure had dropped 1.5 p.s.i. (equivalent to ~0.02 mole of hydrogen), hydrogenation was stopped and the apparatus was disassembled. The bottle was flushed with nitrogen and the contents were filtered through a fritted glass funnel. The methanol solution formed an azeotrope which, after distillation, was extracted with methylene chloride. The methylene chloride extract was distilled, giving methylcycloheptane whose yield was undetermined: bp 134-135° [lit[61] bp 134°]; nmr ($CDCl_3$) δ 1.57 (m, 13) and δ 0.9 (d,3,J = 5.5 Hz, CH-$C\underline{H}_3$).

3. 1-Ethylcyclohexene and Ethylidenecyclohexane

Dehydration of 8 g (0.063 mole) of 1-ethylcyclohexanol (Aldrich) was effected by the addition of 2 g (0.022 mole) of oxalic acid and heating in a distillation flask. The olefin/water azeotrope was collected, and the olefin products were dried after separation from the water phase ($MgSO_4$): bp 136-138° [lit bp 135-136° (1-ethylcyclohexene)[62] and bp 135-136° (ethylidenecyclohexane)[63]]. The nmr

spectrum of the mixture of isomeric olefins indicated that the endo/exo olefin ratio was about 4:1. Nmr (CCl_4) δ 5.32 (m, C=C<u>H</u> for endo olefin), δ 5.07 (m, C=C<u>H</u> for exo olefin), δ 1.91 (m), δ 1.55 (m), and δ 0.96 (t, C—C<u>H</u>$_3$, overlapped with a multiplet from the exo olefin).

F. Miscellaneous Control Experiments

1. Solvolysis of Bicyclo[5.1.0]octane in TFE

Run 15: HBr (0.05 g, 0.0006 mole) was bubbled into 8.9 ml of TFE before 0.13 g (0.00016 mole) of bicyclo[5.1.0]octane (~ 85-90% pure; one impurity apparent) was added. The mixture was heated at 75° for 12 hours. The product distribution (glc) compared remarkably well with that for cyclooctyl bromide solvolysis under the same conditions.

2. Solvolysis of Bicyclo[5.1.0]octane in TFA

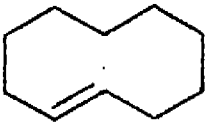
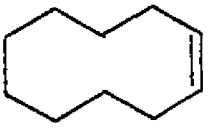
Run 16: Bicyclo[5.1.0]octane (0.106 g, 0.00095 mole) was dissolved in 8 ml (0.12 <u>M</u> in bicyclooctane) of TFA and heated at 73° for 24 hours. The product distribution (glc) was very similar to that obtained for the solvolysis of cyclooctyl halides under the same conditions.

3. Stability of Cyclooctene in TFE

Run 17: Cyclooctene (0.463 g, 0.0042 mole) was dissolved in 21 ml (0.2 <u>M</u> in cyclooctene) of TFE and heated at 75° for 16 hours. Care was taken to remove all traces of acid from the solvent (TFE). Glc analysis revealed that cyclooctene was the sole component in solution after 16 hours of refluxing in TFE. In the presence of traces of acid, substantial amounts of ether were formed with time.

4. Isomerization of trans-Cyclodecene to cis-Cyclodecene in TFE

Run 18: trans-Cyclodecene (0.243 g, 0.00176 mole) and hydrogen chloride (0.076 g, 0.002 mole) were dissolved in 8.8 ml (0.2 M in olefin) of TFE and heated at 75° for 6.5 hours. The olefin was added to the solvent prior to introduction of hydrogen chloride gas. Perhaps some of the isomerization occurred at this stage, before warming the flask. The isomer ratio data are summarized below:

Time (hrs)			
0	94%	6%	(initial composition of sample)
0.033	30%	70%	
0.50	28%	72%	
3.41	8%	92%	
6.50	6.5%	93.5%	

A small amount of ether was found to have formed during the equilibration.

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APPENDIX I

A. Characterization of Deuterium Scrambling

1. Substitution Products

The calculation of percent hydride shift in cyclooctyl chloride may be used as an illustrative example: The nmr spectrum of cyclooctyl chloride (Table IV, run 3) revealed an integration ratio for methine:ring protons ($\underline{H}C\underline{C}l:CH_2$) of 1:32.7. If x is the fraction of deuterium which has been removed from the methine position ($\underline{H}CCl$) (i.e., fraction of hydride shift), then

$$\frac{x}{(14-x)} = \text{nmr}$$

or, where "nmr" = the integration ratio, $\frac{\text{methine proton}}{\text{remainder of ring protons}}$

$$x = \text{nmr}\ (14-x)$$

$$x = 14\ \text{nmr} - x\ \text{nmr}$$

$$x + x\ \text{nmr} = 14\ \text{nmr}$$

$$x\ (1 + \text{nmr}) = 14\ \text{nmr}$$

$$x = \frac{14\ \text{nmr}}{(1 + \text{nmr})}$$

$$\text{or} = \frac{14}{(1/\text{nmr} + 1)}$$

for this example,

$$x = \frac{14}{(1/1/32.7 + 1)} = \frac{14}{33.7} = 0.415$$

or x 100% $\approx$ 42% hydride shift.

Similarly for cyclooctyl-d_1 acetate: $x = \frac{17}{(1/nmr + 1)}$

cyclooctyl-d_5 chloride: $x = \frac{10}{(1/nmr + 1)}$

cyclooctyl-d_5 acetate: $x = 13/(1/nmr + 1)$

cyclooctyl-d_5 chloride: $x = 14/(1/nmr + 1)$

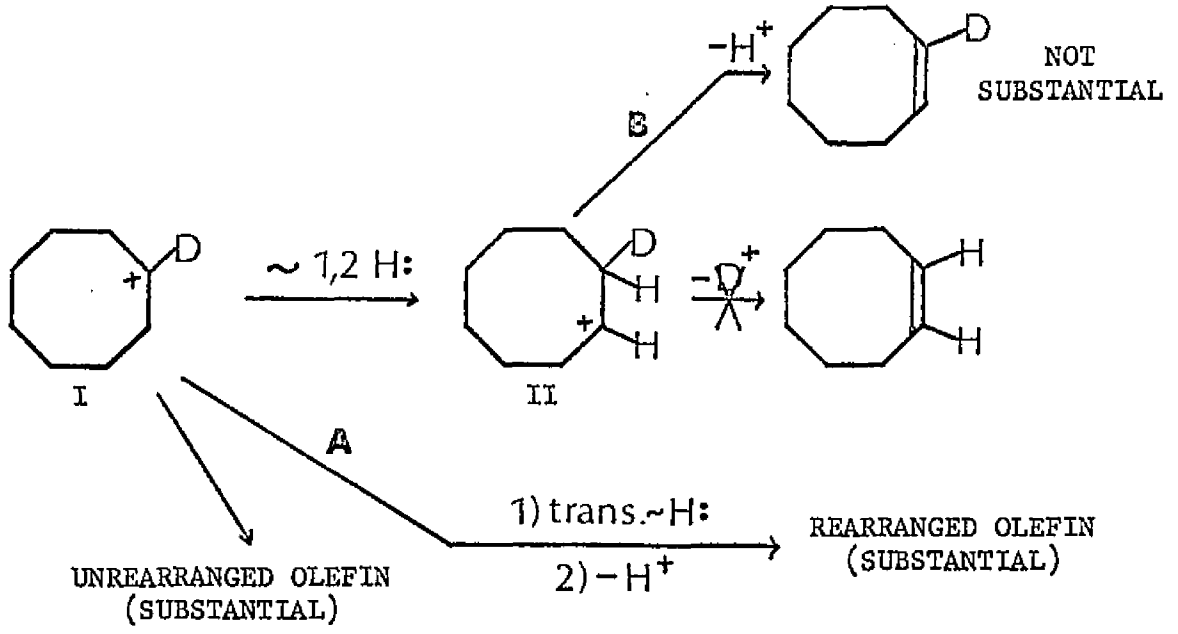
cyclooctyl-d_5 acetate: $x = 17/(1/nmr + 1)$

2. Addition Products: trans-1,2-Dichlorocycloalkanes

The rearrangement reported for dichlorides in Table IV is accurate only if the following assumptions are valid:

a. trans-1,2-Dichlorocyclooctane-d_1

Substantial amounts of olefin are not formed via 1,2-hydride shift and subsequent elimination of deuterium.



This assumption is acceptable since loss of deuterium rather than hydrogen would be unlikely from ion II, due to statistical and isotope effect considerations. It is also assumed that olefin formation via path B does not

account for an appreciable amount of elimination products from rearranged carbonium ions. The olefin formed is trapped and analyzed as 1,2-dichlorocyclooctane.

Nmr integration ratio of $\underline{CH}Cl:CH_2$ = 1:12 (for unrearranged olefin)

= 2:11 (for rearranged olefin)

x (1/12) + y (2/11) = observed nmr ratio = "nmr"

where y = fraction of rearranged dichloride

x = 1 - y = fraction of unrearranged dichloride

so (1 - y)(1/12) + y(2/11) = "nmr", and y = (132 "nmr" - 11/13).

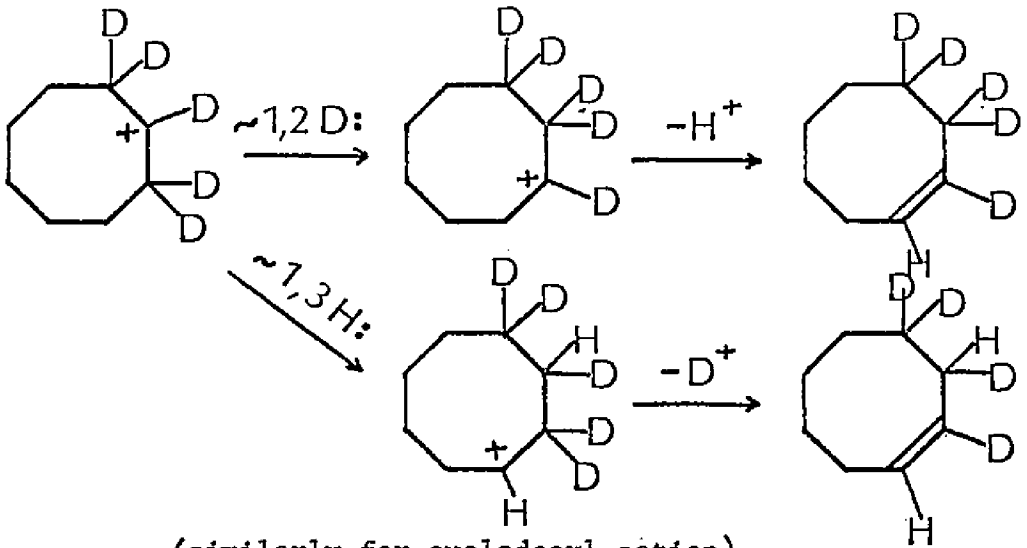
For run 3, Table IV, nmr = 1/10.8

$$y = \left[\frac{(132/10.8) - 11}{13}\right] = 1.2/13 = 0.09$$

or, 0.09 x 10% = 9% hydride shift.

b. <u>trans</u>-1,2-Dichlorocycloalkanes-d_5

Substantial amounts of olefin are not formed in which both hydrogen and deuterium are present at the vinyl (methine for dichloride) position in the same molecule; <u>i.e.</u>, the following is not appreciable,



(similarly for cyclodecyl cation)

(1) trans-1,2-Dichlorocyclooctane-d_5

$$\frac{x(0) + y(2)}{x(10) + y(7)} = \text{"nmr"}$$

$$\frac{2y}{10x + 7y} = \text{"nmr"}$$

since $x = 1 - y$,

$$\frac{2y}{10 - 3y} = \text{"nmr"}$$

$$2y = \text{"nmr"}\ (10 - 3y)$$

$$3y\ \text{"nmr"} + 2y = 10\ \text{"nmr"}$$

$$y(3\ \text{"nmr"} + 2) = 10\ \text{"nmr"}$$

$$y = \frac{10\ \text{"nmr"}}{(3\ \text{"nmr"} + 2)}$$

For run 2, Table V, "nmr" = 1/15.5

$$y = \frac{10/15.5}{3/15.5 + 2} = 10/34 = 0.29$$

or, 0.29 x 100% = 29% transannular hydride shift.

(2) trans-1,2-Dichlorocyclodecane-d_5

$$\frac{x(0) + y(2)}{x(14) + y(11)} = \text{"nmr"}$$

similarly to dichlorocyclooctane,

$$y = \frac{14/26.2}{3/26.2 + 2} = 14/55.4 = 0.25$$

or, 0.25 x 100% = 25% transannular hydride shift.

NMR INTEGRATION RATIOS FOR SYSTEMS TABULATED IN TABLES III AND IV

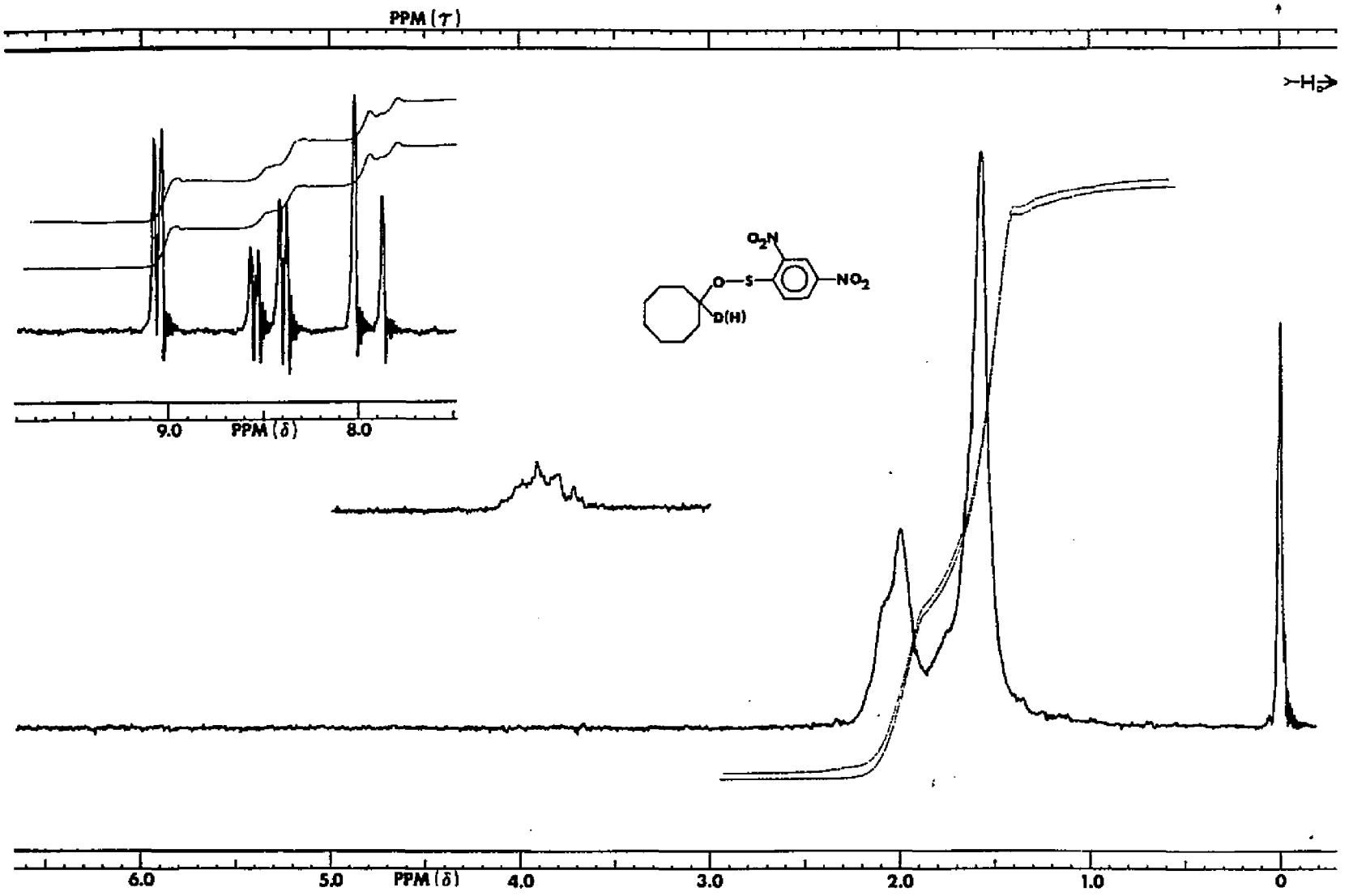
Run	Chloride	Acetate	Dichloride
----------For Table III----------			
1	1:31.0	------	1:10.6
2	1:30.3	------	1:10.6
3	1:32.7	1:33.1	1:10.8
4	------	------	1:8.5
5	------	------	1:8.55
6	------	------	1:85
7	1:32.2	1:32.6	1:8.6
----------For Table IV----------			
1	1:24.6	1:28.6	------
2	1:24.9	1:30.9	1:15.5
3	1:21.3	1:27.7	1:6.4
4	1:46.3	1:58	1:23.0
5	1:47.5	------	1:26.2
6	------	------	1:14.2

B. Formation of Sebacic Acid from Cyclodecyl Chloride

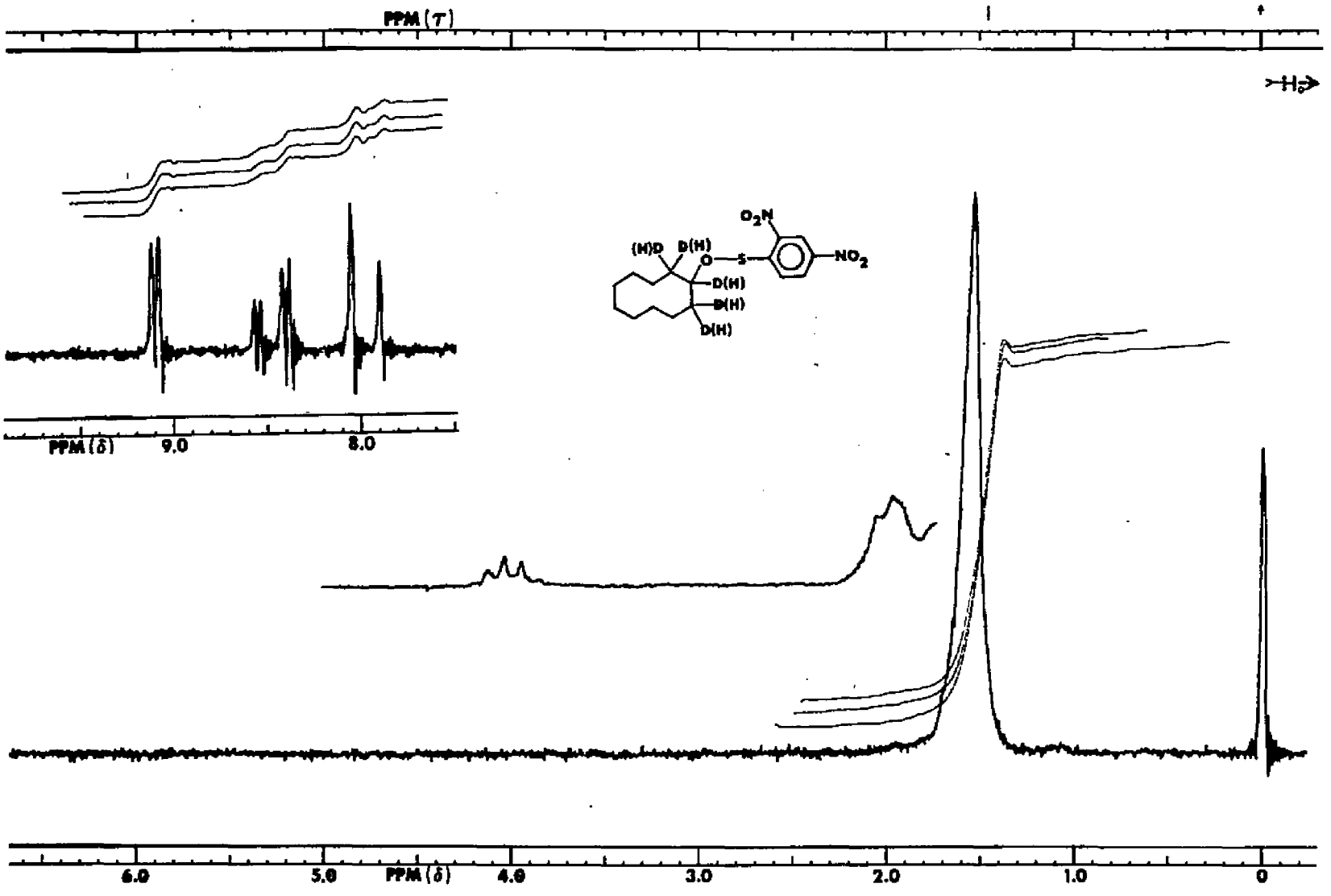
It was noted that distilled samples of cyclodecyl chloride formed small amounts of solid material on standing for extended periods of time. The solid was identified as sebacic acid: (KBr) 3.2-3.5 μ (COO<u>H</u>) and 5.88 μ (C=O); nmr (DMSO-d_6) δ 9.96 (s, 2, COO<u>H</u>), δ 2.20 (m, C<u>H</u>$_2$COOH), and δ 1.30 (m); solubility: aqueous NaOH. <u>Anal</u>. Calcd for $C_{10}H_{18}O_4$: C, 59.4%; H, 8.8%. Found: C, 59.4%; H, 8.9%. Similar solid formation has been observed in samples of cyclooctyl bromide and chloride also.

APPENDIX II

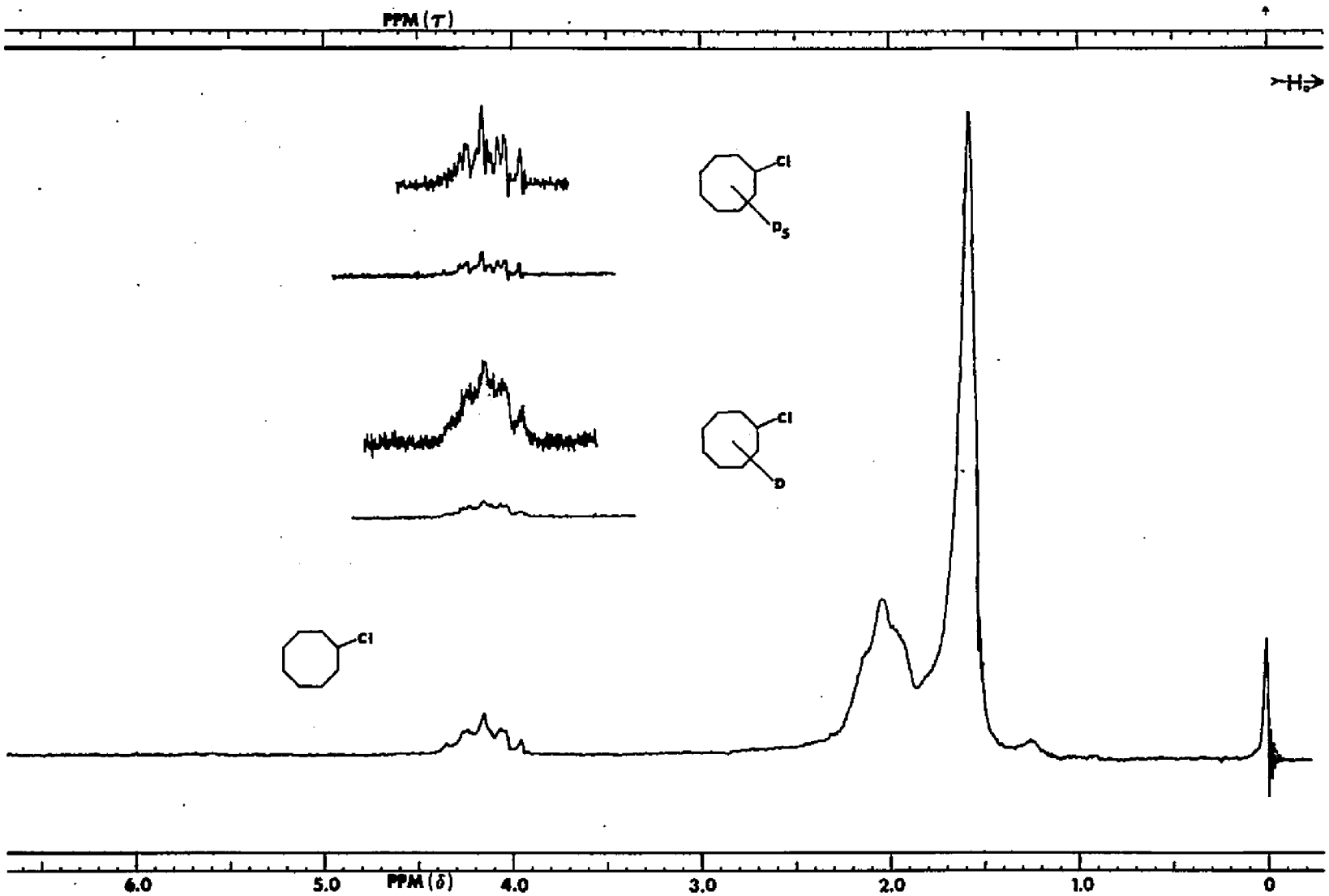
NMR SPECTRA



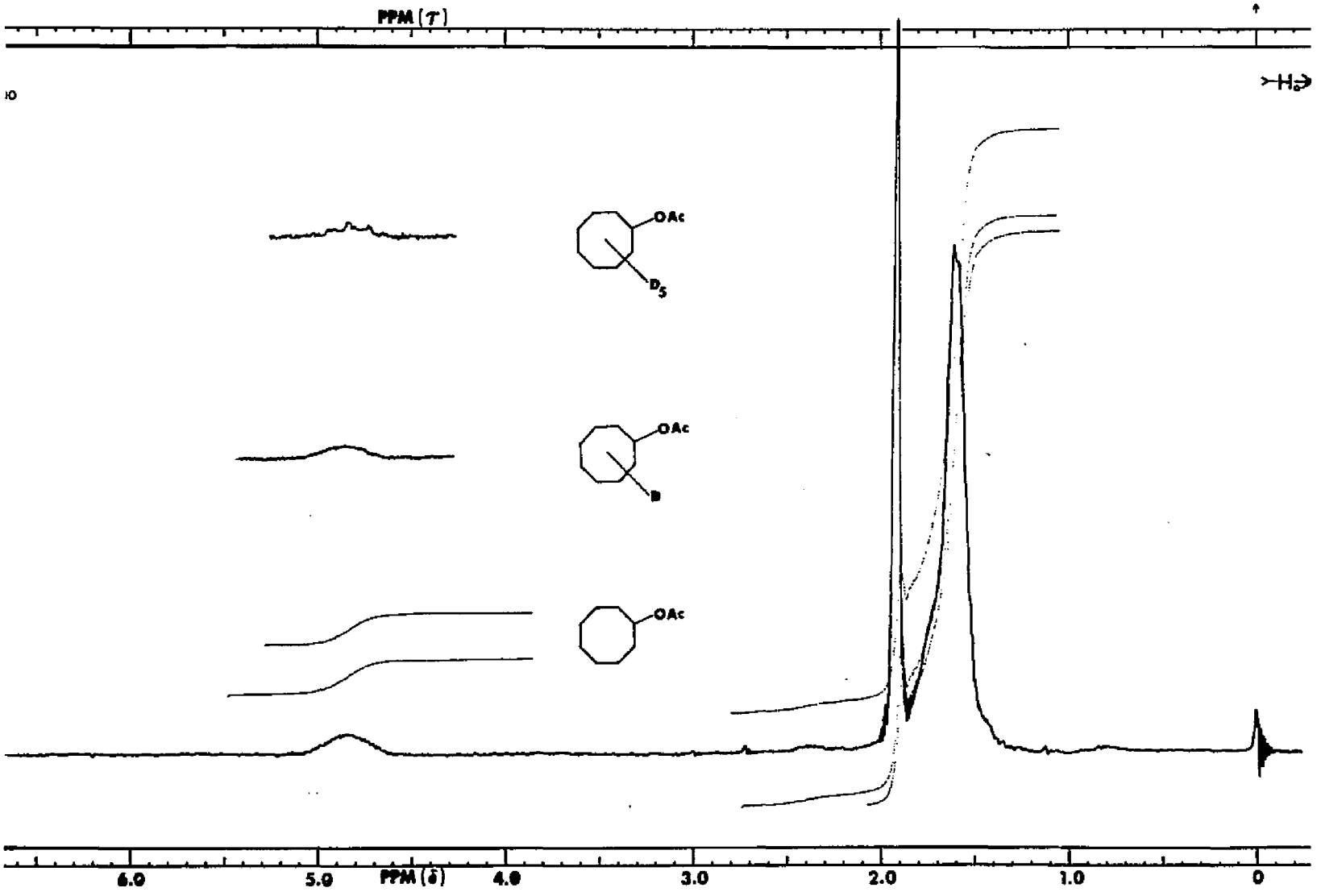
Nmr spectra of monodeuterated and undeuterated cyclooctyl 2,4-dinitrobenzenesulfenate



Nmr spectra of pentadeuterated and undeuterated cyclodecyl 2,4-dinitrobenzenesulfenate



Nmr spectra of cyclooctyl chlorides obtained in the chlorinolysis of arenesulfenates



Nmr spectra of cyclooctyl acetates obtained in the chlorinolysis of arenesulfenates

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VITA

Alan Wayne Foster was born in Norfolk, Virginia, on January 11, 1944. He received his elementary school education in Washington, D. C., and graduated from Stranahan High School in Fort Lauderdale, Florida, in 1962. He entered Tulane University in September of 1962, and was awarded a Bachelor of Science in chemistry in June of 1966. He enrolled in the Graduate School of Louisiana State University in 1966, and after completing his first year of graduate study was married to Karen Jo Pillow in September, 1967. He is currently a candidate for the Doctor of Philosophy degree with a major in Organic Chemistry.

EXAMINATION AND THESIS REPORT

Candidate: Alan W. Foster

Major Field: Chemistry

Title of Thesis: The Effect of Transannular Interactions in Medium Ring Cationic Reaction Intermediates

Approved:

James D. Trawnham
Major Professor and Chairman

Max Goodrich
Dean of the Graduate School

EXAMINING COMMITTEE:

Eugene W. Berg

K. N. Houk

F K Cartledge

James H. Wharton

Date of Examination:

October 27, 1970